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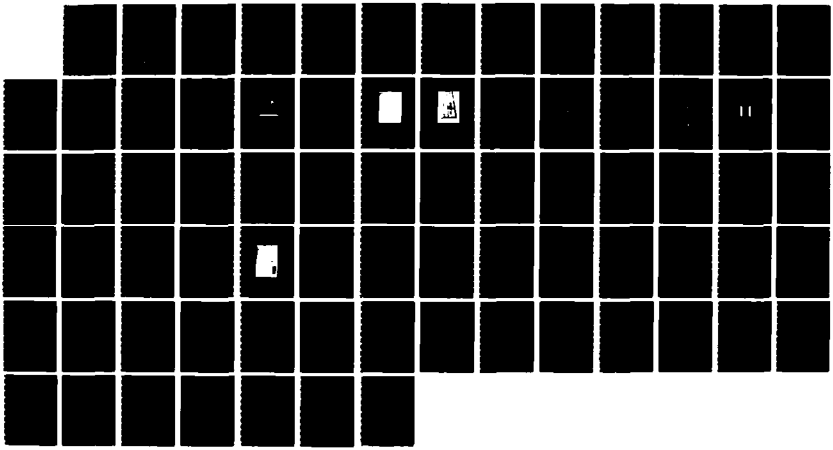

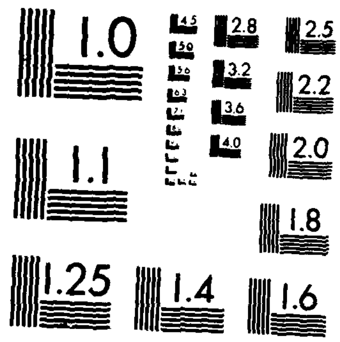

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Criteria for Asphalt-Rubber Concrete in Civil Airport Pavements: Mixture Design

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College Station, Texas

July 1986

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16. Abstract

A mixture design procedure is developed to allow the use of asphalt-rubber binders in concrete for flexible airport pavement. The asphalt-rubber is produced by reacting asphalt with ground, scrap tire rubber to produce the binder for the asphalt-rubber concrete. The report includes procedures for laboratory preparation of asphalt-rubber binders using an equipment setup that was found by researchers to produce laboratory binders with similar properties to field processes.

The rubber-asphalt concrete mixture design procedure includes adjustments to the aggregate gradation to permit space for the rubber particles in the asphalt-rubber binder as well as suggested mixing and compaction temperatures, and compaction efforts. While the procedure has been used in the laboratory to successfully produce asphalt-rubber concrete mixtures, it should be evaluated in the field to ensure that consistent results can be achieved in a production environment.

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METRIC CONVERSION FACTORS

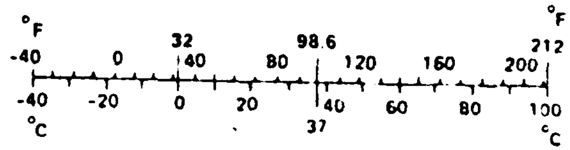
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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We also want to extend our thanks to two consultants who provided valuable literature and special help in preparing the specifications for field preparation of asphalt-rubber materials: Drs. Rudy Jimenez and Ray Pavlovich. Thanks also is due to Dr. Scott Shuler and Cindy Adams who coordinated their work with ours so that the most effective use of available research funds could be realized.

PREFACE

This report is the result of a project sponsored by the Federal Aviation Administration, U.S. Department of Transportation, and conducted by the Texas Transportation Institute (TTI) of Texas A & M University. Several elements of the work were performed on a cooperative basis with other ongoing projects at TTI during the period 1982-1985. The projects were:

(1) Contract No. DTFH61-82-C-00074 which resulted in a report titled "Investigation of Materials and Structural Properties of Asphalt-Rubber Paving Mixtures" by Shuler, Pavlovich, Epps, and Adams, and

(2) TTI Study No. 2-9-83-347 which resulted in a report TTI-2-9-83-347-1F titled "Asphalt-Rubber Binder Laboratory Performance" by Shuler, Adams, and Lamborn.

The elements of cooperation involved laboratory preparation and testing of asphalt-rubber binders, securing asphalt-rubber materials from field projects included in TTI Study No. 347, developing the asphalt-rubber concrete mixture design procedure, and in material characterization of prepared asphalt-rubber concrete specimens. As a result of this cooperation there are several sections of this report that are similar to sections of the previously mentioned reports.

This is the first of two reports on contract number DTFA 01-83-C-30076 "Criteria for Asphalt-Rubber Concrete in Civil Airport Pavements" and it includes the general work with asphalt-rubber binders and the development of the mixture design procedure. The second report will include the material characterization of the asphalt-rubber concrete, cost-effectiveness analysis and construction procedures.

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CHAPTER 1. INTRODUCTION

HISTORY

The blending of ground tire rubber and asphalt cement has been attempted by various investigators in the past with varying levels of success. Charles H. McDonald, Consulting Engineer, Phoenix, Arizona (formerly Materials Engineer with the City of Phoenix) is considered to be the father of the asphalt-rubber systems developed in the United States. Mr. McDonald's laboratory work which was initiated in 1963, resulted in the placement of patching materials in the mid 1960's.

These early experiments included the introduction of various forms of rubber (including latex, devulcanized or reclaimed rubber, raw and ground vehicle tire rubber) and various types and percentages of rubber. Because of its lower cost and promising performance in field experiments, the use of ground waste tire rubber was selected for extended studies. The patching material patented by McDonald was called a "Band-Aid" and consisted of ground scrap vehicle tire rubber (retained between the 16 and 25 mesh sieves) and Los Angeles basin asphalt cement. The ground rubber content was 25 percent by weight of the total asphalt-rubber binder. The two materials were blended at approximately 375°F for 20 minutes. The "Band-Aid" treatment for localized patching received only limited attention from the engineering community.

McDonald continued his experimental work with the City of Phoenix and initiated research efforts with Atlas Rubber, Inc. In the late 1960's, the Arizona Department of Transportation (ADOT) under the direction of Gene Morris, began working with McDonald in an effort to develop a process for spraying the asphalt-rubber binder. Several experimental test sections were placed at Phoenix Sky Harbor International Airport (1966) and on U.S. 80 near downtown Phoenix. Sahuaro Petroleum Asphalt Company (Sahuaro) became interested in the product and cooperated in testing its applications in seal coats. Several small test sections were placed at the airport and on City of

Phoenix streets and in 1968 an asphalt-rubber seal coat was placed on frontage roads and access ramps of the Black Canyon Freeway by ADOT. From 1968 to 1971, development was directed toward improved procedures for application and in 1971 ADOT placed a 13-mile test section on Interstate 40 near Winslow, Arizona which contained experimental sections with asphalt-rubber binders. On these test sections high boiling point kerosene was reacted with the asphalt-rubber mixtures to provide the desired spraying viscosities.

In 1975 Arizona Refining Company (ARCO) began experimental work with asphalt-rubber binder systems. Arizona Refining Company's first experimental section was placed in 1975. The result of the experimental work conducted by McDonald, ADOT, Sahuaro and ARCO has led to the use of asphalt-rubber as a potential binder system in about 35 states and several Canadian Provinces on over 10,000 lane-miles of roadway. Many of the agencies have used the material on an experimental basis but several have extensive experience including both Arizona and Texas.

Two national conferences have clearly shown widespread interest in the unique properties of asphalt-rubber in highway pavements and have addressed both success and failures of experimental projects. These conferences and others have shown the need for additional information on performance, relationships between laboratory developed properties and performance, design techniques for specific applications, specifications and tests for compliance, and construction practices. While recent work has helped to define more clearly some of those areas of concern, there is a continued need to define the circumstances in which these various treatments can best be used to solve the maintenance problems encountered.

OBJECTIVES

The primary objectives of this research are to

1) Develop processes for preparing asphalt-rubber binders in the laboratory that have properties similar to those produced in the field.

2) Modify the FAA laboratory asphalt concrete mixture design procedure for use with these asphalt-rubber binders

3) Determine the engineering properties of typical asphalt-rubber concrete materials

4) Perform a cost-effectiveness analysis to determine if these materials should be considered as alternatives in future designs

5) Develop model specifications and construction procedures for the use of these materials in the field.

SCOPE

Work described in this report includes that conducted to achieve objectives one and two and part of objective five. A second report will cover the balance of the project activities.

This report specifically includes the development of the laboratory procedure for preparing asphalt-rubber for use in mixture design, the development of the mixture design procedure, and the guide specifications for field production of the asphalt-rubber binders.

CHAPTER 2. LABORATORY TESTING AND PRODUCTION OF ASPHALT-RUBBER BINDERS

LABORATORY TESTING OF ASPHALT-RUBBER BINDERS

Concerted attempts have been made to evaluate asphalt-rubber binders by applying laboratory tests developed for specification testing and characterization of asphalt cements. Few reported attempts show that asphalt cement tests can be successfully used to evaluate asphalt-rubber binders. Repeatibility of many of the asphalt cement tests depend on uniform consistency of the asphalt. Because asphalt-rubber is a blend of asphalt and fine rubber particles, the discrete nature of the rubber particles produces considerable variation in test results.

A variety of laboratory tests for characterizing asphalt-rubber materials have been evaluated by researchers such as Pavlovich, Shuler, and Rosner (Ref 1), Shuler and Hamberg (Ref 2), Jimenez (Ref 3), Oliver (Ref 4), and Chehovits, Dunning, and Morris (Ref 5). The laboratory tests investigated for application to asphalt-rubber binders are shown in Table 1. A brief summary of the experience of these researchers with these tests is included in the following sections.

Softening Point

Ring and Ball softening point was one of the first tests used to measure physical properties of asphalt-rubber in an attempt to develop criteria for differentiating between different mixtures. Pavlovich, Shuler, and Rosner (Ref 1) showed that the test was of only limited use and recommended modifications to the test method. Shuler and Hamberg (Ref 2) modified the test, evaluated asphalt-rubber binders and found that the modified test (Double Ball Softening Point, see Figure 1) was more accurate than the original test in identifying mixture differences produced by variations in rubber content and digestion time. Shuler (Ref 6) reported that double ball softening point test results were sensitive to rubber concentration and

Table 1. Laboratory Tests Used to Characterize Asphalt - Rubber

Laboratory Procedure	Reference No. 1	2	3	4	5
Ring and Ball Softening Point	x				
Absolute Viscosity at 140°F	x				
Ductility at 39.2°F and 77°F	x		x		
Double Ball Softening Point (Phase Change Temperature)		x			
Force Ductility	x	x			
Constant Stress (Schweyer) Rheometer	x	x			
Sliding Plate Microviscometer/ Rheometer				x	x
Falling Coaxial Cylinder Viscometer			x		

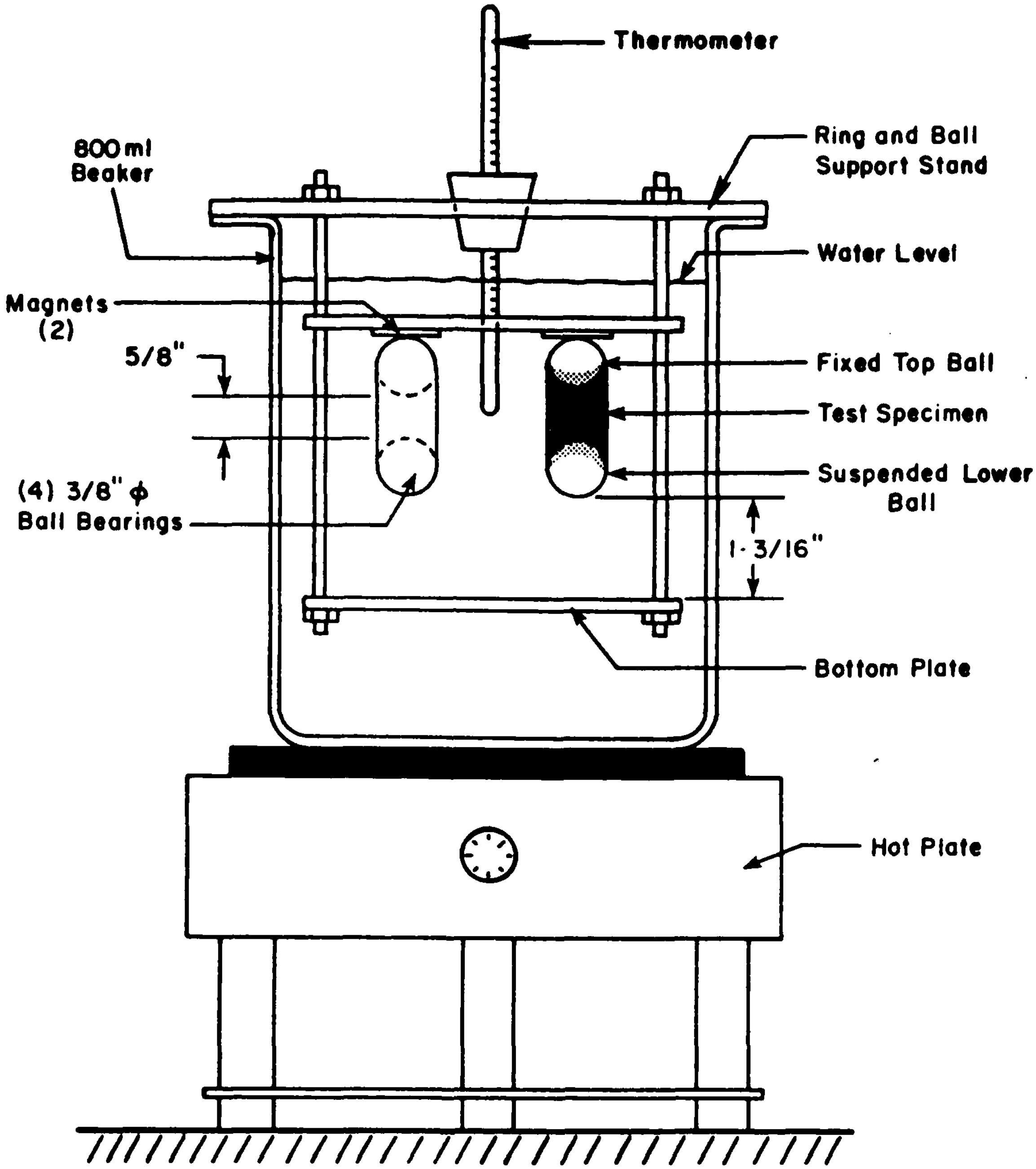


Figure 1. Double Ball Softening Point Apparatus.

digestion and that the test could be used to develop optimum behavior of asphalt-rubber mixtures by adjusting rubber content and digestion conditions.

Absolute Viscosity

Some of the earliest research with asphalt-rubber rheology was accomplished with large capillary viscometers (Ref 1). Using reduced vacuums and unusually large capillary diameters, absolute viscosity measurements were made on a large variety of asphalt-rubber mixtures to determine the precision of the test and to collect high temperature viscosity data. Results of tests using these devices showed high variability and that the lack of homogeneity of the asphalt-rubber produces effects at the tubewall and at the meniscus (see Figure 2) that make these viscometers unsuitable for use in either research or routine quality control programs.

Ductility

Ductility values have been determined at both 39.2 and 77°F using standard ductility equipment and procedures for asphalt-rubber binders (Refs 1 & 3). The results of tests were not sensitive to test temperature nor to the length of time held at the digestion temperature but were sensitive to digestion temperature. Because this test was sensitive to digestion temperature, researchers modified the test to develop information on the stiffness and force required to elongate the specimens. Such a test was first used by Anderson and Wiley (Ref 7) to study the forces required to elongate asphalt cements. Anderson and Wiley (Ref 7) modified the standard test by adding a force ring in place of the briquet plate. Pavlovich, Shuler, and Rosner (Ref 1) added an LVDT to monitor the deformation of the proving ring while Shuler and Hamberg (Ref 2) modified the specimen mold to produce a specimum with a constant one square centimeter cross-section for a length of six centimeters. This geometry allowed engineering properties of stress, strain, and modulus of elasticity to be determined. This modified test is called the force-ductility test, see Figure 3. While the seven parameters obtained from test results (Ref 6) can predict changes in asphalt-rubber properties due to rubber type, rubber concentration, and digestion level,

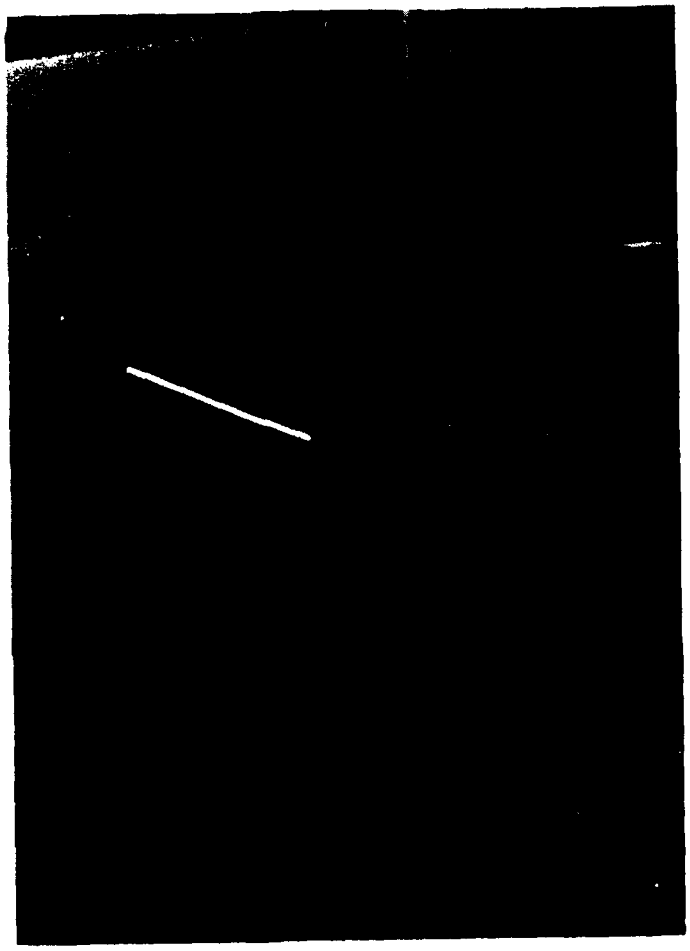


Figure 2. Appearance of Meniscus of Asphalt Rubber Material in a Viscometer Tube.

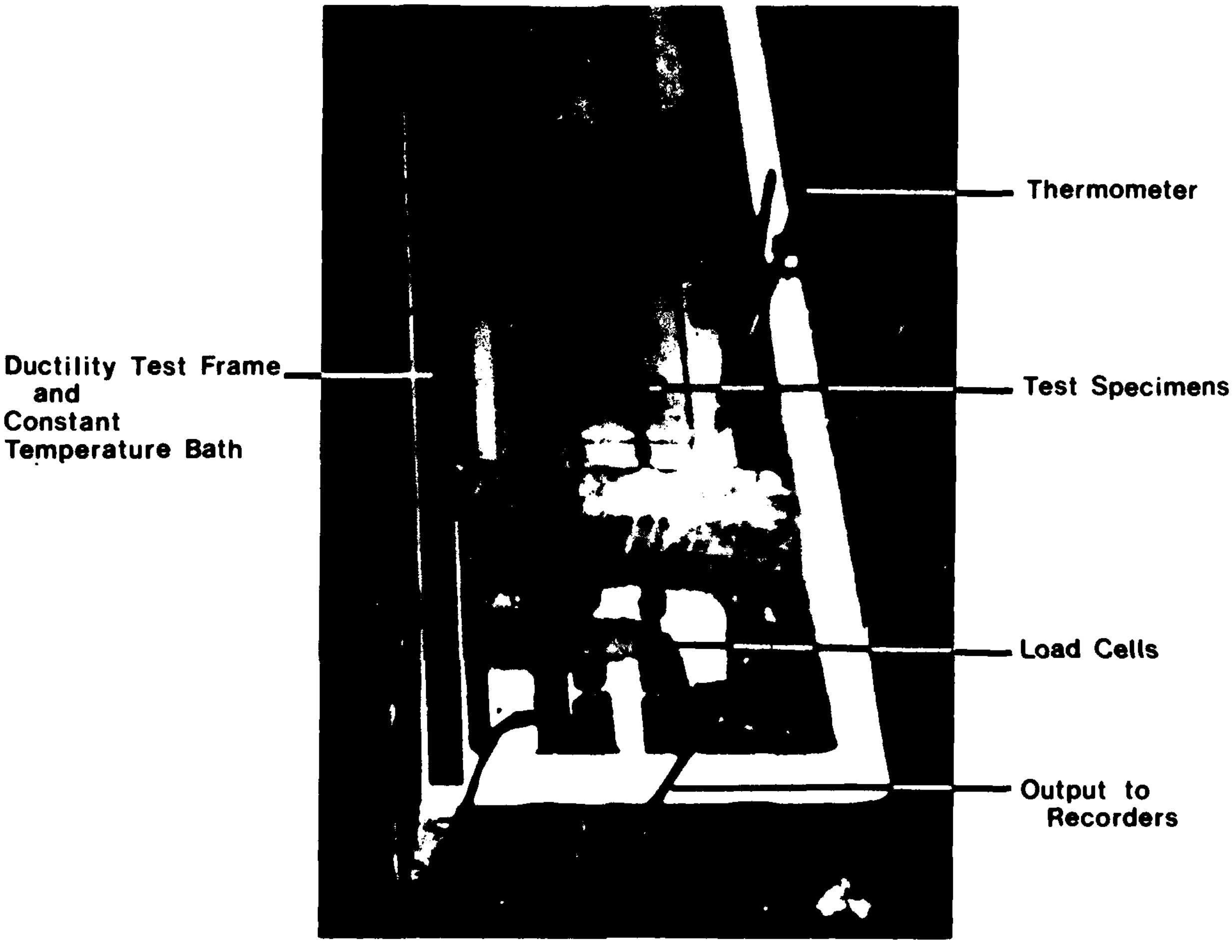


Figure 3. Force-Ductility Testing Machine.

experience with the test and interpretation of test results is not sufficiently developed for use in specifications to define acceptable and unacceptable performance.

Constant Stress Rheometer

A device of this type developed by Schweyer (Ref 8) has been used extensively in asphalt-rubber research (Refs 1, 2, & 3), see Figure 4. A measure of apparent viscosity can be determined for various material types under a range of temperatures. The variability in asphalt-rubber viscosities associated with many other viscometers is absent for data generated with the Schweyer Rheometer when used properly and within an appropriate temperature range. A large quantity of data for a wide assortment of mixtures has been reported by researchers in Arizona and New Mexico (Refs 1 and 2). Early work (Ref 1) suggested the means for reducing variability in Schweyer data, and later work (Refs 2 & 3) utilized these recommendations to improve testing techniques. The Schweyer Rheometer is one of a few statistically verified techniques currently available for measuring apparent temperature-viscosity characteristics for asphalt-rubber mixtures. However, this test procedure does not lend itself to production testing for specification acceptance purposes.

Sliding Plate Microviscometers

These viscometers have been used not only to measure viscosity of asphalt-rubber binders but also to measure the elastic recovery of these binders. The fundamental orientation of the output from this apparatus makes it desirable because the output describes fundamental material characteristics. The small test specimen size, however, may contribute to high data variability, making some differences between mixtures difficult to discern.

Since the elastic properties of asphalt are improved with the addition of rubber, tests to indicate the level of improvement have been devised. These tests have historically been rebound tests. A tensile strain is imparted to the material, then released, and the strain recovery measured. At least two

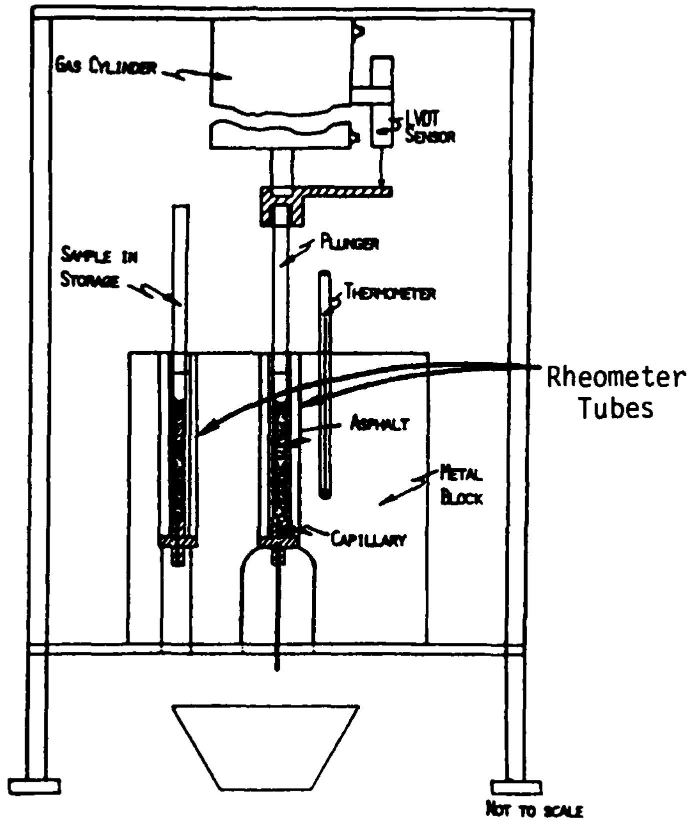


Figure 4. Schematic Diagram of Schweyer Rheometer.

investigators (Refs 4 & 5) have used modified parallel plate viscometers for this purpose. The results are sensitive to mix differences and give an indication of potential field benefits depending on the level of elasticity. The apparatus used by Oliver (Ref 4) is shown in Figure 5. In his work, Oliver (Ref 4) showed that reaction time and temperature can influence elastic recovery as well as type and concentration of rubber. He also showed that an asphalt-rubber mixture produced in the laboratory had similar characteristics to one produced in the field using the same materials and reacted at the same temperature for the same length of time. Oliver found that the morphology of the rubber particles produced by the manufacturing process significantly affected the elastic response of the binder but that the size of the particles did not. Oliver (Ref 4) concluded that cryogenically produced rubber particles were unsuitable for use in asphalt-rubber binders used in pavements.

While these investigations showed the value of the sliding plate microviscometers in detecting changes in the behavior of various asphalt-rubber binders, the test procedures and interpretation of results do not lend themselves to use in specification testing.

Falling Coaxial Cylinder

Jimenez (Ref 9) has successfully used the falling coaxial cylinder to measure differences in viscosity for various asphalt-rubber mixtures. Generally, trends found with the Schweyer rheometer were corroborated with the falling coaxial cylinder. In addition, it may be possible to perform tests at higher temperatures with the coaxial cylinder than with the Schweyer rheometer.

A diagram of a typical falling coaxial cylinder is shown in Figure 6. Even though the device is simple it suffers from the same shortcomings as the Schweyer rheometer for production work and in use for material specifications.

Summary

While several of these test procedures offer promise in characterizing the behavior of asphalt-rubber or in detecting differences between various combinations of components, none appears to be suitable for use in

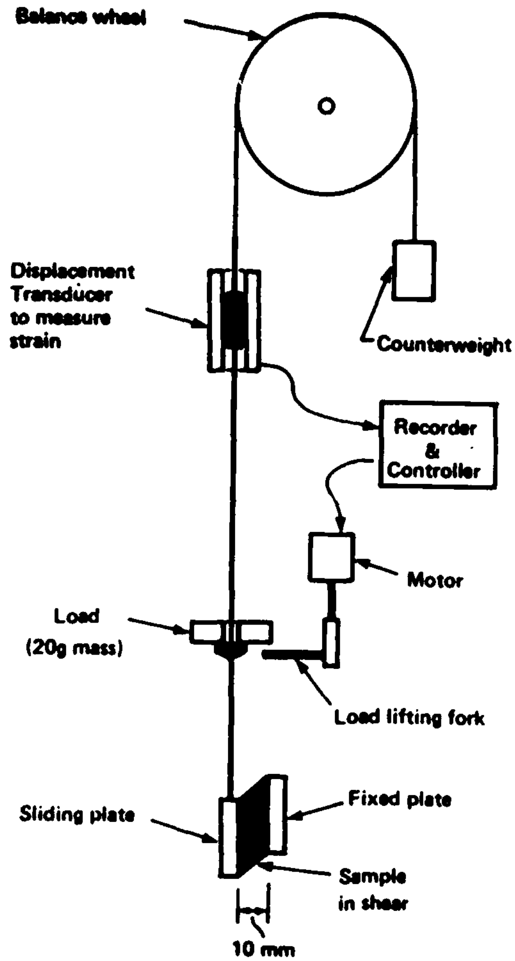


Figure 5. Diagram of Sliding Plate Viscometer Set-Up Used to Measure Elastic Recovery of Strain.

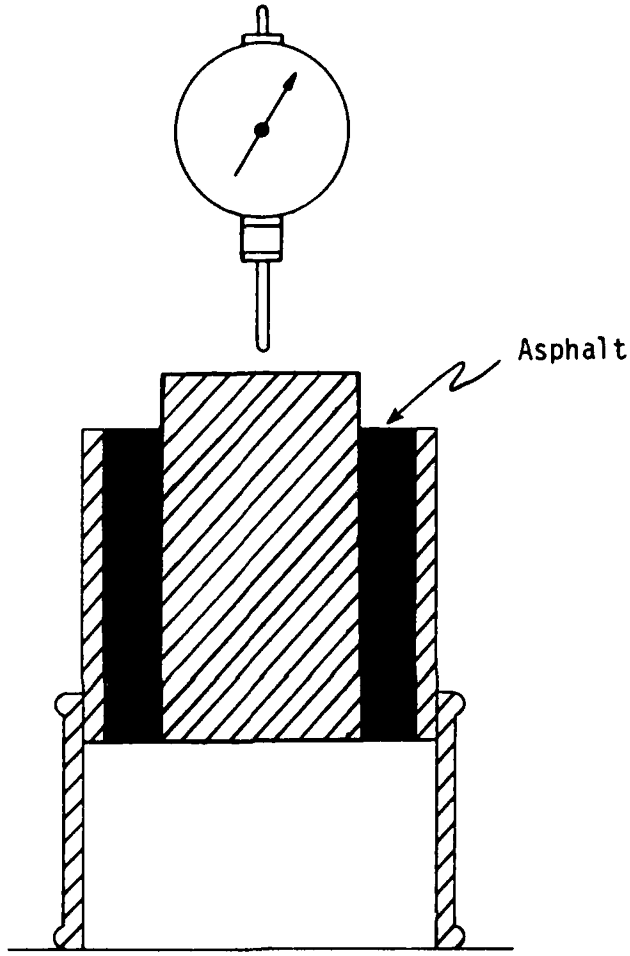


Figure 6. Schematic of a Falling Coaxial Cylinder.

combinations of components, none appears to be suitable for use in specification testing of these materials. Indeed none of the research to date has been directed toward defining the characteristics that an asphalt-rubber binder should have in order to meet prescribed performance requirements for a particular pavement application.

One of the most significant problems faced by the asphalt technologist is that there are no behavioral models that adequately describe the function of the binder in an asphalt aggregate system. Because behavioral models do not exist, technologists continue to use correlations between tests, such as the ring and ball softening point, and engineering properties such as stiffness developed by Shell researchers during the 1950's and 60's. These methods appear to work for asphalt cements and have been organized into well developed, comprehensive design procedures that use asphalt properties such as viscosity, bitumen stiffness, and ring and ball softening point. Design methods such as the Shell Pavement Design Guide (Ref 10) cannot be applied to asphalt-rubber binders without extensive testing programs to develop the relationships between binder characteristics and binder-aggregate mixture properties.

The effect of this situation on the current study is that procedural or recipe methods must be used in preparing the asphalt-rubber mixtures both for laboratory studies and full scale field projects until more fundamental relationships can be developed. The following sections of this chapter contain a discussion of the properties of and the recommended laboratory procedures for preparing asphalt-rubber mixtures.

FACTORS AFFECTING PROPERTIES OF ASPHALT-RUBBER MATERIALS

Background

Rubber has been incorporated in asphalt roadways since the beginning of this century (Ref 11). Early asphalt-rubber combinations used natural rubber in the asphalt. Natural rubber is susceptible to oxidation and, when overheated, the rubber converted to an oil with the result that the beneficial properties dissipated rather rapidly with time (Ref 12). These deficiencies were overcome with the advent of synthetic rubber which was compounded and vulcanized to resist heat and weathering. While the synthetic rubber lacked the solubility in asphalt of natural rubber, it could be reacted with asphalt to produce many of the same characteristics but much larger quantities of synthetic rubber were required.

While the synthetic rubber could be reacted with asphalt, in some cases the rubber appeared to absorb the oils out of the asphalt leaving blends that exhibited poor adhesive properties (Ref 12). Researchers found that asphalts with low aromatic oil contents produced these dry blends. This problem was apparently overcome when rubber from ground, whole truck tires, which have approximately 18 percent natural rubber (Ref 13) was added to the blend. When this high natural rubber scrap was added to hot asphalt, it exhibited the desired sticky elastic character of the early natural rubber blends but had greater heat stability than the virgin natural rubbers.

Using the knowledge developed from an extensive period of trial investigations, formulations of asphalt, extender oil, and scrap rubber have been developed that produce an asphalt-rubber material with the desired characteristics. The next section of this report includes a brief discussion of several factors that affect the properties of asphalt-rubber blends.

Rubber Factors

The factors which most influence the formulation of asphalt-rubber are included below. Most of these factors have been investigated thoroughly. While most are known to be important in asphalt-rubber production, their effect on specific performance related factors is not well understood.

Rubber Type. A wide assortment of scrap rubber is available for use in asphalt-rubber systems. The chemical composition of the rubber varies depending on the sources of the scrap such as automobile tires, and truck or bus tires, and whether the rubber is tread peel or whole carcass rubber. LaGrone (Ref 14) defined the terms relating to the processing of scrap rubber and provided typical compositions of scrap rubbers available for the production of asphalt-rubber binders and these are shown in Table 2. The selection of the

TABLE 2. Chemical Composition of Typical Scrap Rubber Products Available for Asphalt-Rubber

	AUTO TIRES (Whole)	TRUCK TIRES (Whole)	AUTO TREAD	TRUCK TREAD (Mixed)	TRUCK TREAD (Precured)	DEVULCANIZED WHOLE TIRE
Acetone Extractables (%)	19.0	12.5	21.0	16.0	18.5	20
Ash (%)	5.0	5.0	5.0	4.0	4.0	20
Carbon Black (%)	31.0	28.5	32.0	30.0	32.0	20
Total Rubber Hydrocarbon (TRH) (%)	46.0	54.0	42.0	50.0	45.5	40
Synthetic Rubber (%)	26.0	21.0	37.0	23.0	40.5	22
Natural Rubber (%)	20.0	33.0	5.0	27.0	5.0	18

type of rubber affects the elasticity of the resulting asphalt-rubber (Refs 1, 2, 4, 5, 13) and the stability of the reacted product (Ref 12).

Rubber Processing Method. The way the scrap rubber is processed has a significant effect on the behavior of the rubber when mixed with hot asphalt and on the properties of the resulting material. Oliver (Ref 4) reported that rubber morphology (structure) was the most important factor affecting elastic properties of asphalt-rubber binders. Shuler (Ref 6) showed differences in asphalt-rubber viscosity betwen rubbers of different morphology but the effect of morphology was confounded by rubber particle size and natural rubber content differences.

Oliver (Ref 4) included electron micrographs of rubber particles to show the differences between the surface morphology of particles ground at ambient temperature and those ground below the embrittlement temperature (i.e., cryogenically ground). The differences in surface morphology affect the rubber surface area available to the asphalt and therefore affect the rate at which the reaction occurs.

In addition to rubber morphology, the size of the rubber particles and whether the rubber has been processed after grinding, i.e., devulcanized, both affect the rate of reaction of the asphalt-rubber (Refs 12, 13). These last two factors affect the type of asphalt selected for the digestion process (Ref 15) more than the engineering properties of the asphalt-rubber produced (Refs 4, 6).

Rubber Concentration. Asphalt-rubber, as currently used, includes between about 15 and 28 percent by total weight of dry rubber in an asphalt cement matrix. The rubber concentration is acknowledged by all researchers to significantly affect the properties of the reacted asphalt-rubber binder. Specifying agencies with little experience with asphalt rubber materials will often use the general specifications of a supplier. These specifications include the proportions of the asphalt-rubber components, the specifications for each component, and the blending times and temperatures. Indeed specifications from states ranging from Texas (Ref 16) to New York (Ref 17) to Arizona (Ref

15) appear to be quite similar in style and content indicating that the product being produced is fairly well defined in terms of materials and processes.

Researchers studying the properties of asphalt-rubber blends all indicate that rubber concentration significantly affects the properties being measured. The effect of rubber concentration on elastic recovery found by Oliver is shown in Figure 7. Similar levels of strain recovery have been reported by Chehovits, Dunning, and Morris (Ref 5) for six different rubbers and two different asphalt cements as shown in Figure 8.

Reaction Temperature/Mixing Time. The combination of reaction temperature and mixing time has been shown by numerous investigators to be a very important factor affecting asphalt-rubber properties (Refs. 1, 2, 4, & 6). Figure 7 shows the effect of length of mixing time at a constant temperature on elastic recovery. Based on these test results it is possible to conclude that rubber concentration could be reduced while the length of mixing is increased and a prescribed elastic recovery could be achieved. Although this may be true, Shuler (Ref 6) has shown that as the mixing time increases the amount of solid rubber in the mixture begins to be reduced. Shuler verified these findings by extracting the solid rubber from the asphalt-rubber mixture and also by performing gel permeation chromatography (GPC) tests on the virgin asphalt and on the asphalt after mixing with the rubber. The GPC results shown in Figure 9 indicate that the molecular weight distribution has been shifted at both the high and low ends. This means that as digestion continues, some rubber may be lost to the asphalt fraction of the mixture. Huff and Vallerga (Ref 12) also discuss the reaction of natural rubber in asphalt cement and point out that when scrap high in natural rubber is added to an asphalt cement the resulting blend exhibits the same characteristics as those shown by mixtures of only natural rubber and asphalt. The major difference between these 2 types of mixtures is that the conversion of the synthetic rubber is slower because the rubber is vulcanized. However, the resulting mixture is more heat stable than the natural blends and is, as a result, more forgiving of delays in the field.

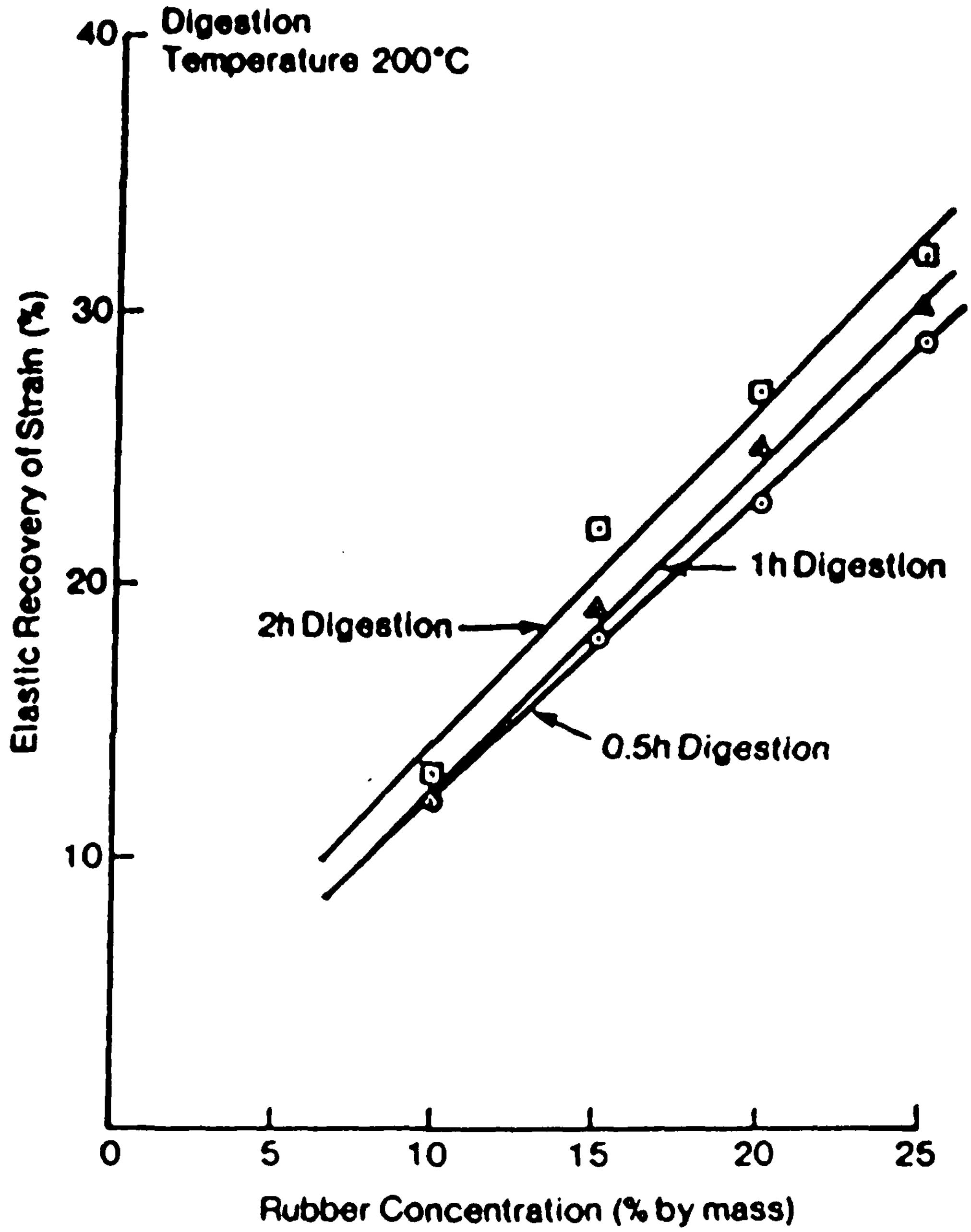
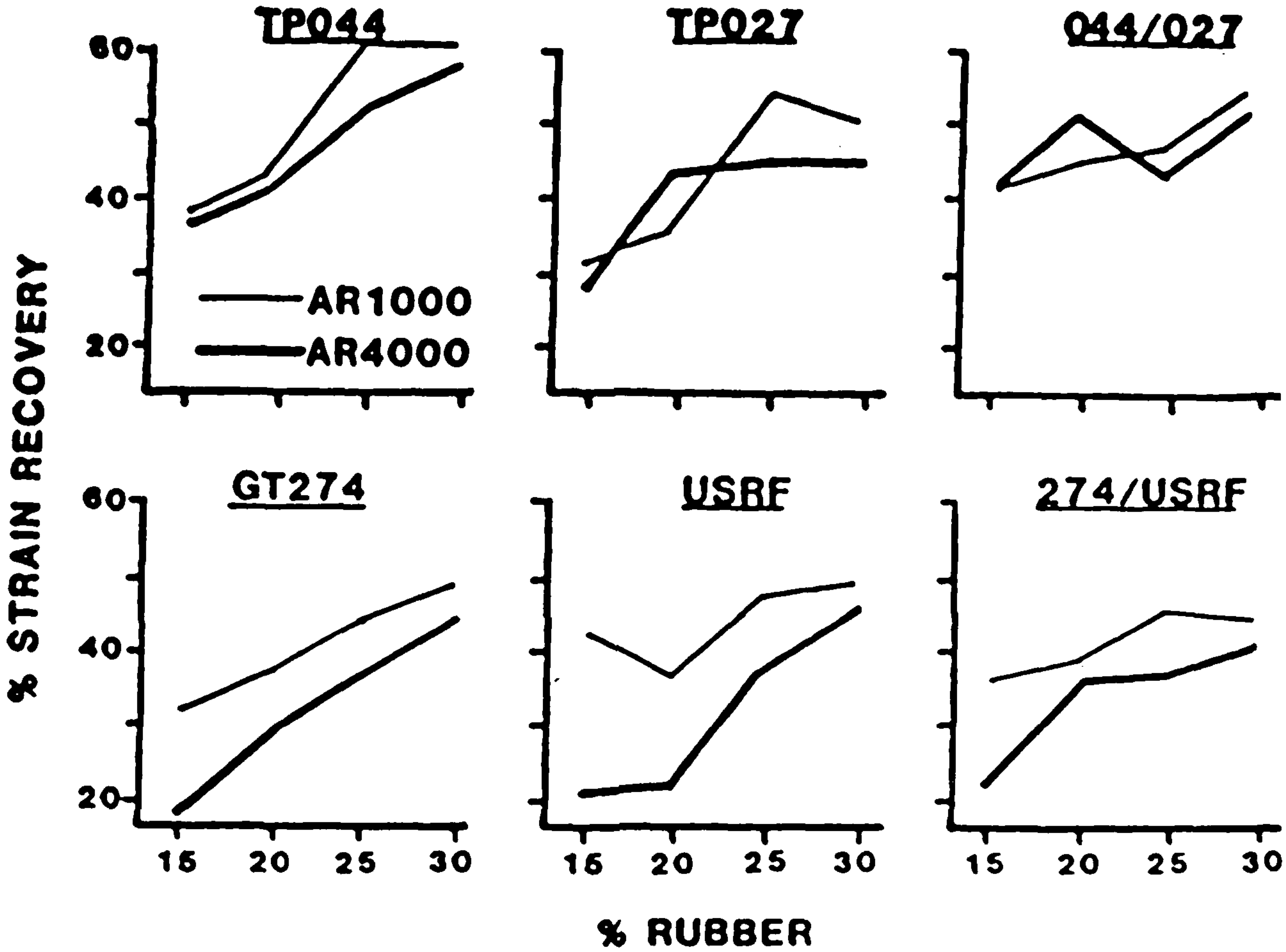


Figure 7. Effect of Rubber Concentration on Elastic Recovery. (Reference 4)



TP044, TP027: ATLOS Rubber Designations
044/027: 50/50 Blend of TP044 and TP027
GT274, USRF: US Rubber Designations
274/USRF: 50/50 Blend of GT274 and USRF

Figure 8. Effect of Rubber Concentration on Elastic Strain Recovery. (Reference 5)

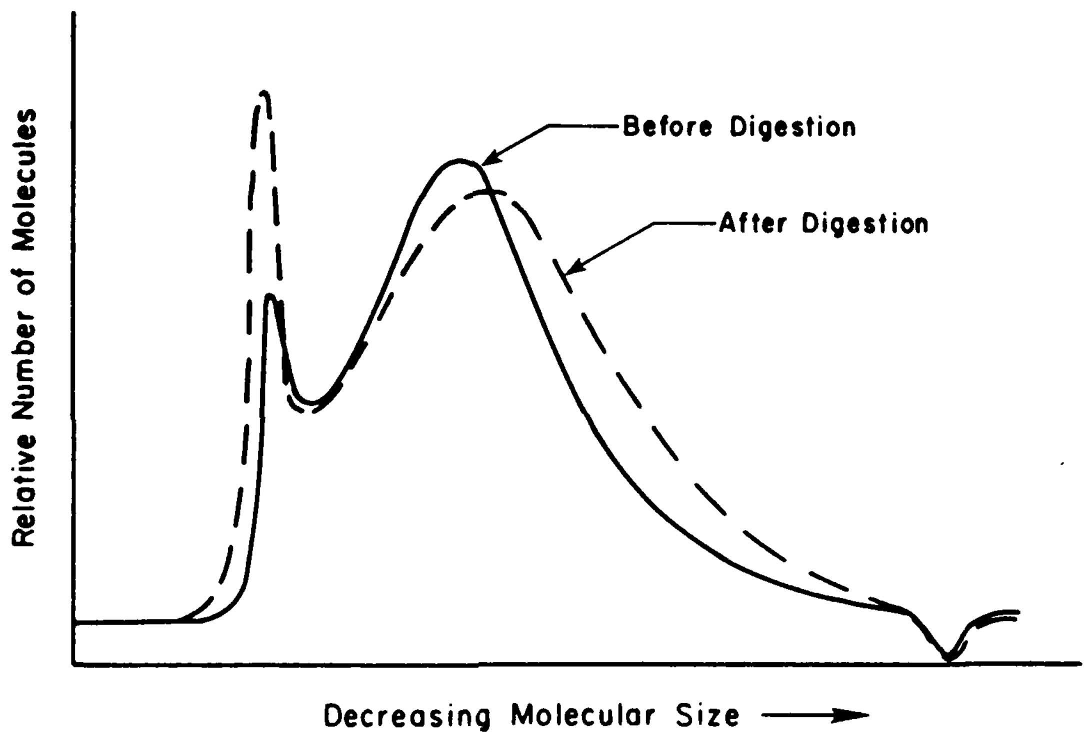


Figure 9. Gel Permeation Chromatography Results on an Asphalt Cement Before and After Digestion with Scrap Rubber. (Reference 6)

Shuler (Ref 6) has also shown that, even though various combinations of mixing temperature and time may be selected, observing the viscosity characteristics of the mixture during digestion can allow termination of the mixing process at a relatively constant viscosity level (Figure 10). Monitoring the viscosity and temperature of the mixture in the field can also allow materials to be prepared in the laboratory that have the same digestion level as measured by the viscosity. That materials can be produced in the laboratory that have properties similar to those produced from the same ingredients in the field has been verified by both Shuler (Ref 6) and Shuler, Adams, and Lamborn (Ref 18). However, Shuler, et al. (Ref 18) indicated that the low level of field digestion did not produce mixture properties corresponding to low level digestion in the laboratory. Rather, low level field digestion was somewhere between low and moderate laboratory levels.

It is possible, however, to produce in the laboratory asphalt-rubber mixtures that are similar to those typically produced in the field. The next section of this chapter describes laboratory production of asphalt-rubber materials.

LABORATORY PRODUCTION OF ASPHALT-RUBBER

A variety of techniques has been used in the laboratory to produce asphalt-rubber materials. These techniques vary from the use of open containers for reaction of the asphalt-rubber (Ref 15) to a closed system described by Shuler, Adams, and Lamborn (Ref 18). Apparently both systems can be used to produce asphalt-rubber materials suitable for laboratory evaluations. All of the processes described in the literature require continuous stirring of the asphalt-rubber during digestion.

Reaction times in laboratory studies have varied from 0.5 to 2 hours at temperatures typically ranging from 325 to 450°F. Evaluating the effect of reaction time has been both in terms of the change in viscosity of the asphalt-rubber with reaction and in terms of the properties of the reacted asphalt-rubber. Oliver (Ref 4) investigated the effect of both reaction time and temperature on elastic recovery strain of natural and synthetic rubbers.

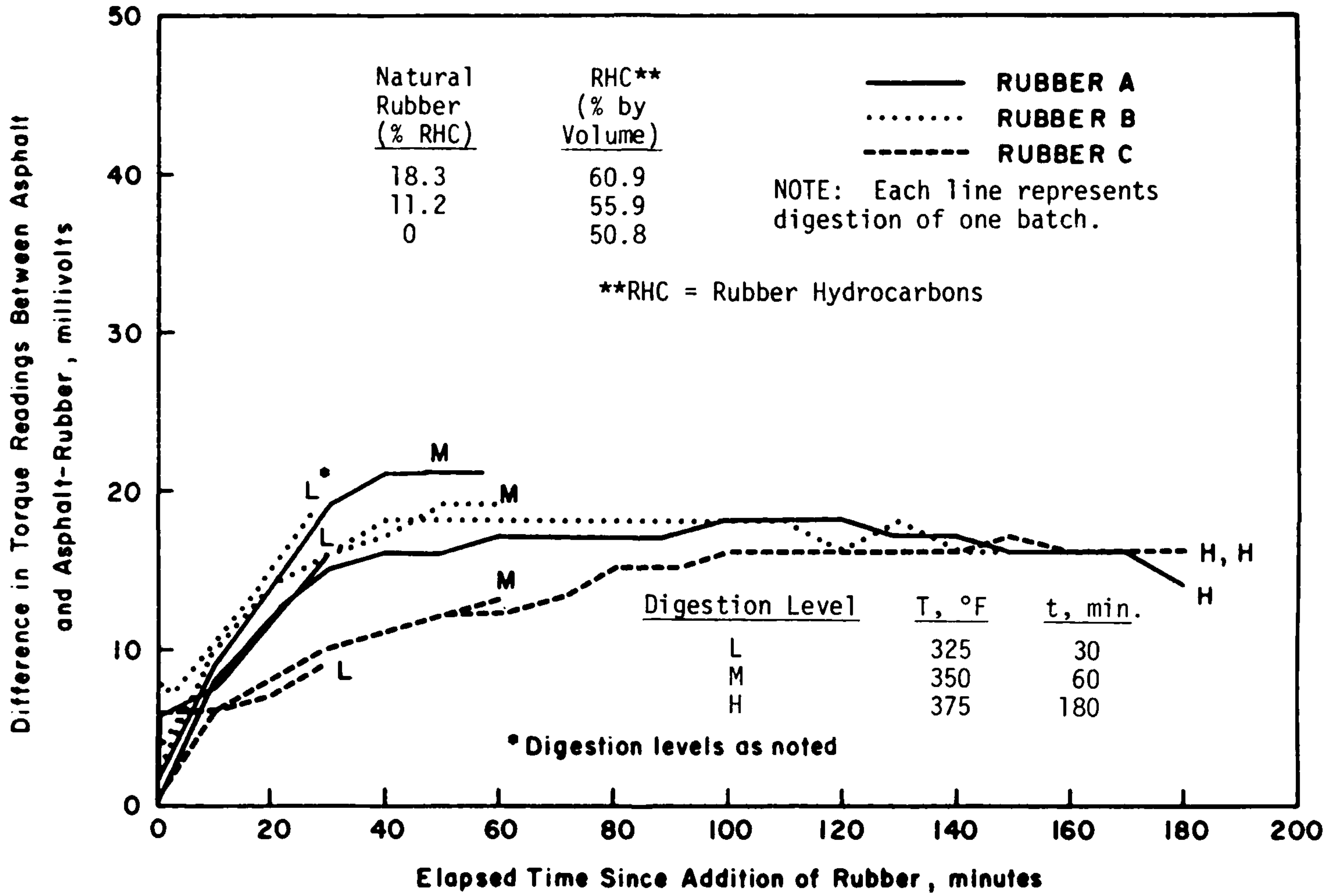


Figure 10. Torque Fork Output for Three Rubbers Used in El Paso, Texas, at 22 Percent Rubber and Three Digestion Levels. (Reference 6)

See Figures 11 and 12 respectively. The plots in Figure 11 show very clearly the interaction between time and temperature of digestion on elastic recovery and that the properties of natural rubber can be significantly reduced by too long a reaction time. Notice in Figure 11 that the peak of elastic recovery shifts toward a lower temperature as the length of digestion time increases and that the elastic recovery drops off sharply for the 2-hour digestion time when temperature exceeds 425°F. Figure 12 shows that the synthetic rubber is much more stable at the higher digestion conditions than the natural rubbers. However for 2 hours of digestion above 425°F the elastic recovery of the synthetic rubber levels out and would no doubt begin to drop as the temperature rises above 460°F.

Shuler, Adams, and Lamborn (Ref 18) conducted a study to evaluate the effect of rubber type, concentration, and digestion conditions on viscosity and properties of the resultant asphalt-rubber binders. They included a series of plots that show clearly the influence of several of these factors. See Figures 10, 13, and 14. All three of these rubbers were vulcanized with rubbers A and B ground under ambient conditions while rubber C was cryogenically ground. By reviewing these three figures it is evident that at least the medium level of digestion is required for the asphalt-rubber to achieve a stable viscosity within a reasonable length of time and probably the high level temperature (375°F) is the most appropriate since most of the mixtures reach a stable viscosity within one hour. Notice too that rubber C is the slowest reacting mixture, since it has no natural rubber and was cryogenically ground. However, rubbers A and B both appear to reach stable viscosities at 375°F after one hour of digestion.

A survey of laboratory reaction conditions for selected literature indicates that the combinations in Table 3 have been studied. Based on this survey, the results contained in Figures 10 through 14, and Shuler's (Ref 6) comparison of viscosities of rubber asphalts produced in both the field and laboratory, the authors recommend that laboratory mixing be performed at 375°F for one hour or until the viscosity versus time plot is relatively

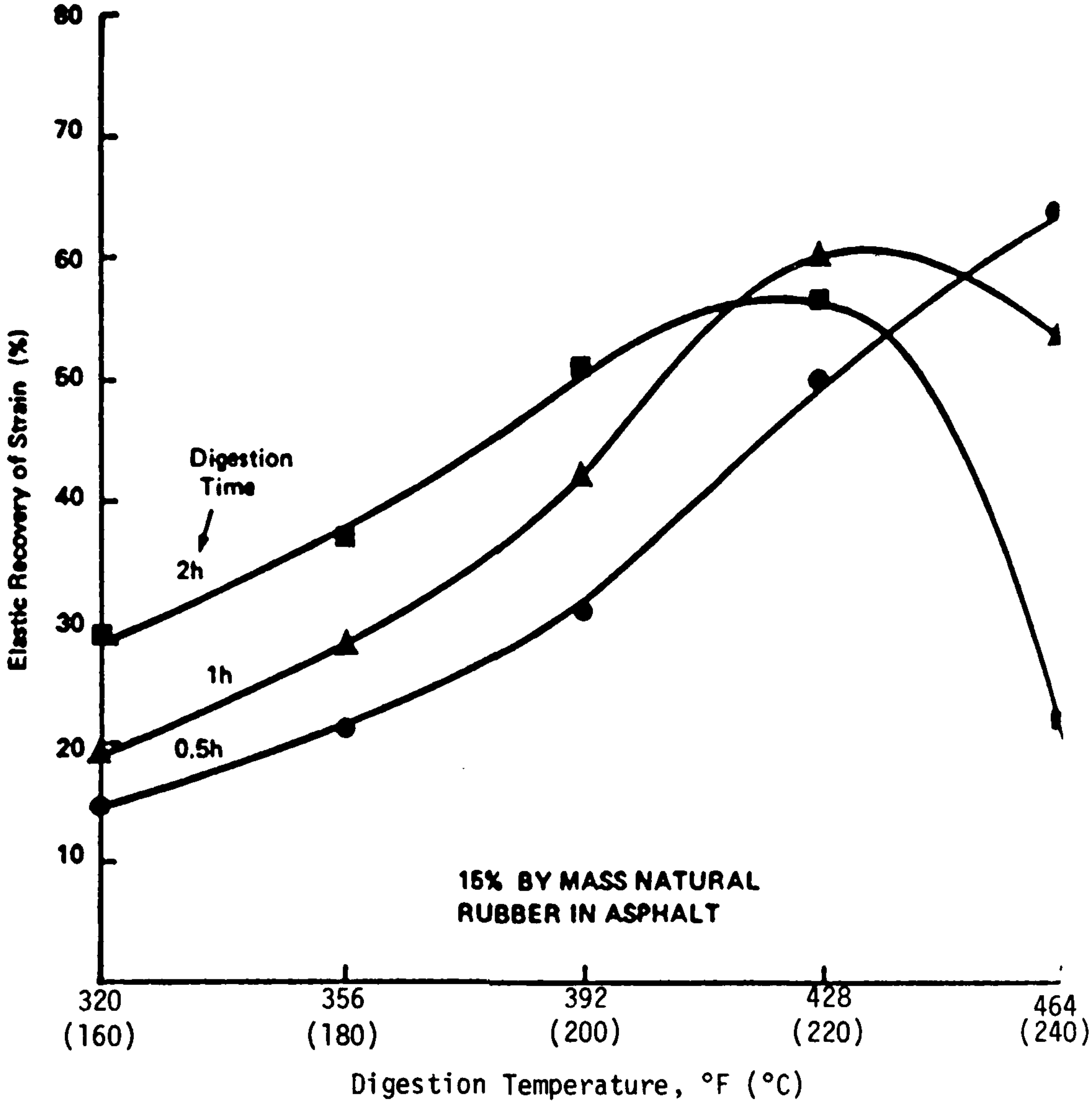


Figure 11. Effect of Digestion Time and Temperature on Elastic Recovery for Asphalt-Rubber from Natural Rubber Tire Buffings. (Reference 4)

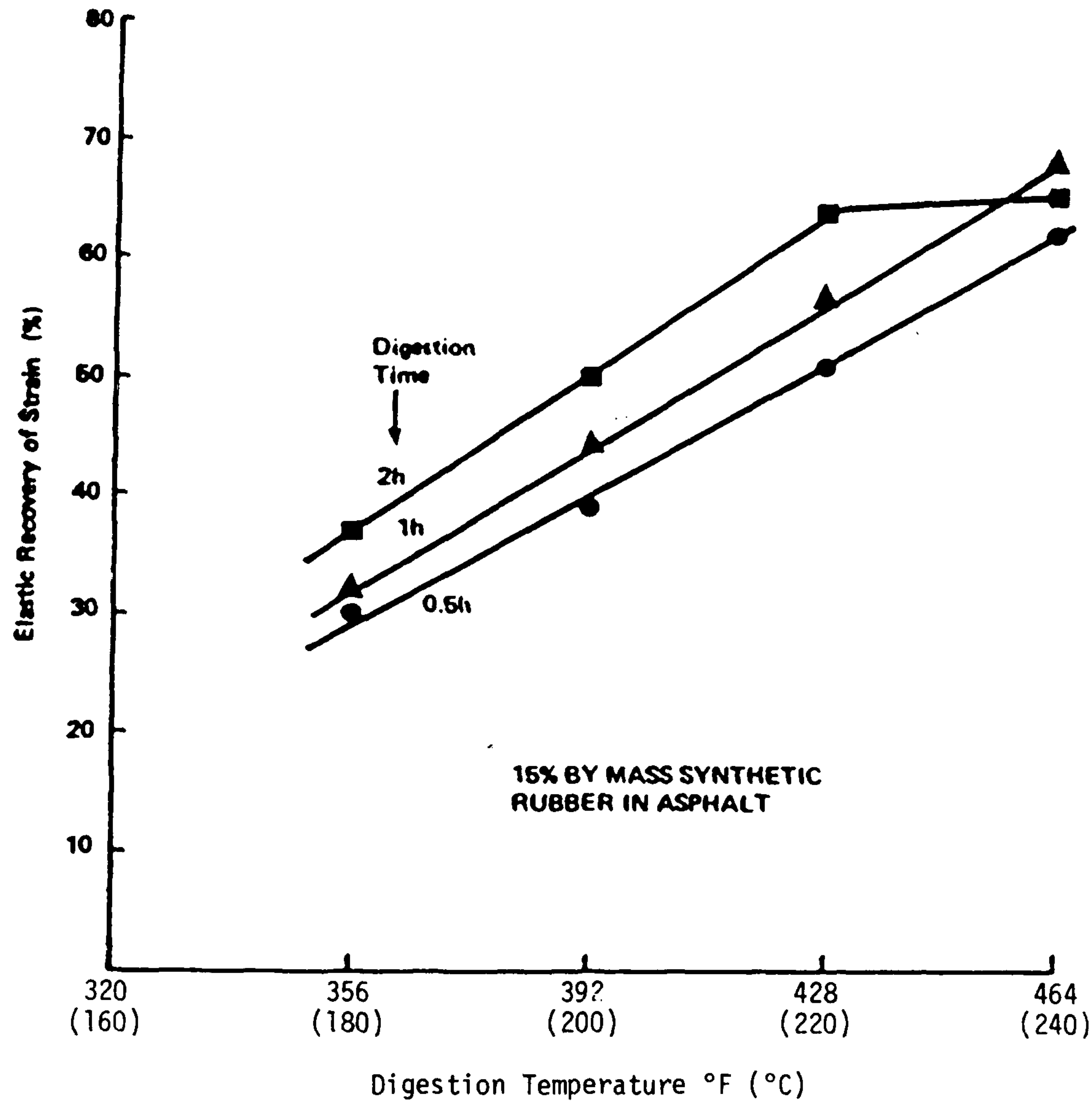


Figure 12. Effect of Digestion Time and Temperature on Elastic Recovery for Asphalt-Rubber from Synthetic Rubber Tire Buffings. (Reference 4)

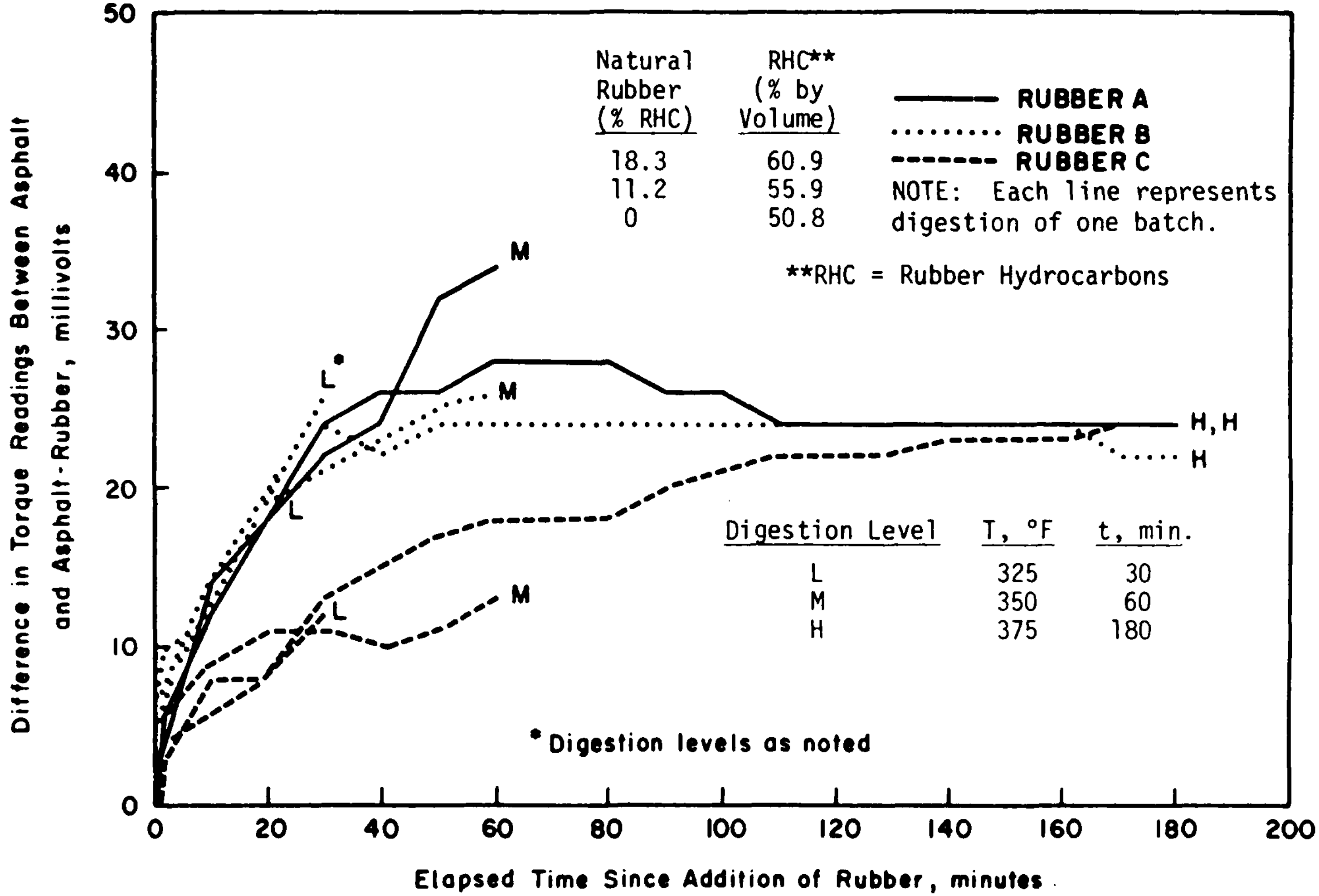


Figure 13. Torque Fork Output for Three Rubbers Used in El Paso, Texas, at 24 Percent Rubber and Three Digestion Levels. (Reference 6)

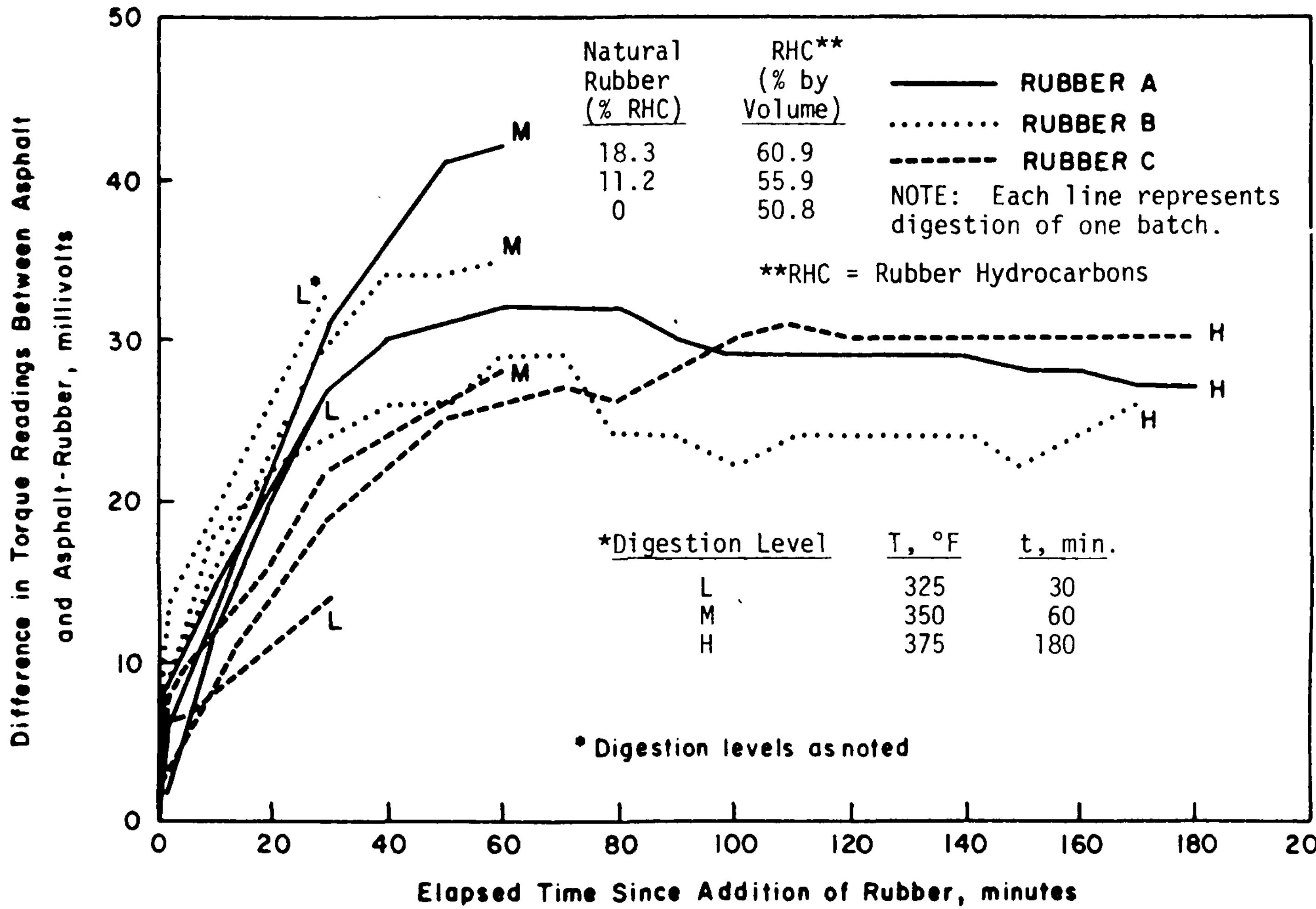


Figure 14. Torque Fork Output for Three Rubbers Used in El Paso, Texas, at 26 Percent Rubber and Three Digestion Levels. (Reference 6)

TABLE 3. Asphalt-Rubber Reaction Conditions Investigated

Reference Number	Reaction Conditions Studied	
	Temperature, °F	Time, Minutes
1	350, 375, 400	30, 60, 120
2	325, 375, 425	60
3, 9, 15	375	30
4	320, 356, 392, 428, 464	30, 60, 120
6, 18	325, 350, 375	30, 60, 180
19	392	t>60

constant. A suggested procedure that includes recommendations for equipment and digestion levels is included in the following section.

SUGGESTED PROCEDURE FOR LABORATORY PRODUCTION OF ASPHALT-RUBBER

Equipment

The following list of equipment is recommended for digestion of asphalt with rubber to produce binders for use in asphalt-rubber concrete mixture design:

1. Induction Motor Stirrer - variable torque, constant speed motor capable of operating at 500 rpm to monitor viscosity and automatically adjust motor power to maintain selected speed.
2. Proportional Temperature Controller to maintain temperature in reaction kettle to within +/- 0.10°C for temperatures up to 250°C. Power available to heaters shall be approximately 750 watts.
3. Electric Heating Mantle for round bottom 2000 ml flash with thermocouple and power output from 500-750 watts.
4. Three Neck reaction flask with 24/40 ground glass joints.
5. Teflon bearing for stirring rod used with 1 above. [Can be custom made or scavenged from a closed system stirrer for vacuum work such as Fischer 14-513-100 stirrer for vacuum work or Cole-Parmer K-4740-00 closed system stirrer with 24/40 glass joint.]
6. Ring stand and supporting equipment.
7. Optional-strip chart recorder for monitoring output of induction motor stirrer.

Procedure

The suggested procedure is based largely on the experience of Shuler and fellow researchers in a series of research projects conducted in Arizona, New Mexico, and Texas during the period from 1977-1985 (Refs 1, 2, 6, 9, & 18). The proposed procedure is based on the assumption that the reaction of the asphalt-rubber should continue until a stable viscosity (torque from the stirrer) is achieved. Even though a stable viscosity can be achieved using a variety of mixing times and temperatures, a particular combination is suggested in order to provide guidance in preparing suitable materials for use in asphalt-rubber concrete mixture design. A typical equipment setup for production of the asphalt-rubber is shown in Figure 15.

The proposed reaction system consists of a constant speed motor with a propeller stirrer for constant agitation of the asphalt-rubber. Heat is supplied through an electric heating mantle and is monitored and adjusted by an electronic temperature controller.

The stirrer acts as a rotational viscometer which can measure relative changes in fluid viscosity during digestion. Estimates of viscosity can be secured by calibrating the output from the stirrer with viscosity measurements made on the same material at the same temperature using a Haake portable rotational viscometer model VT-02 or a Brookfield viscometer. Shuler, Adams, and Lamborn (Ref 18) reported such a correlation between the torque fork (variable torque stirrer) output in millivolts and the Brookfield viscosity in centipoises shown in Figure 16. Notice that the coefficient of determination is 99 percent and is very satisfactory for controlling the mixing process and for correlating laboratory viscosity with viscosity during digestion in the field.

Samples of the materials to be used by the contractor should be provided for use in preparing the asphalt-rubber. Samples shall be secured using appropriate statistical sampling procedures to ensure that representative materials are obtained. Materials to be sampled include: the asphalt cement, the rubbers, and diluents. The asphalt cement shall be stored in sufficiently small quantities that multiple reheating is avoided.

Step 1. Heat approximately 1000 ml of the asphalt slowly and stir to avoid local overheating. Once the asphalt is fluid add the appropriate amount to the 2,000 ml reaction flask; also add diluent if included in the mixture. Insert the mixer propeller, continue heating the asphalt, and increase the mixer speed to 500 rpm.

Step 2. When the asphalt cement reaches 375°F, add the proper blend of rubber to the flask through the neck. Add the rubber as quickly as possible, in approximately 10 seconds. Begin digestion time as soon

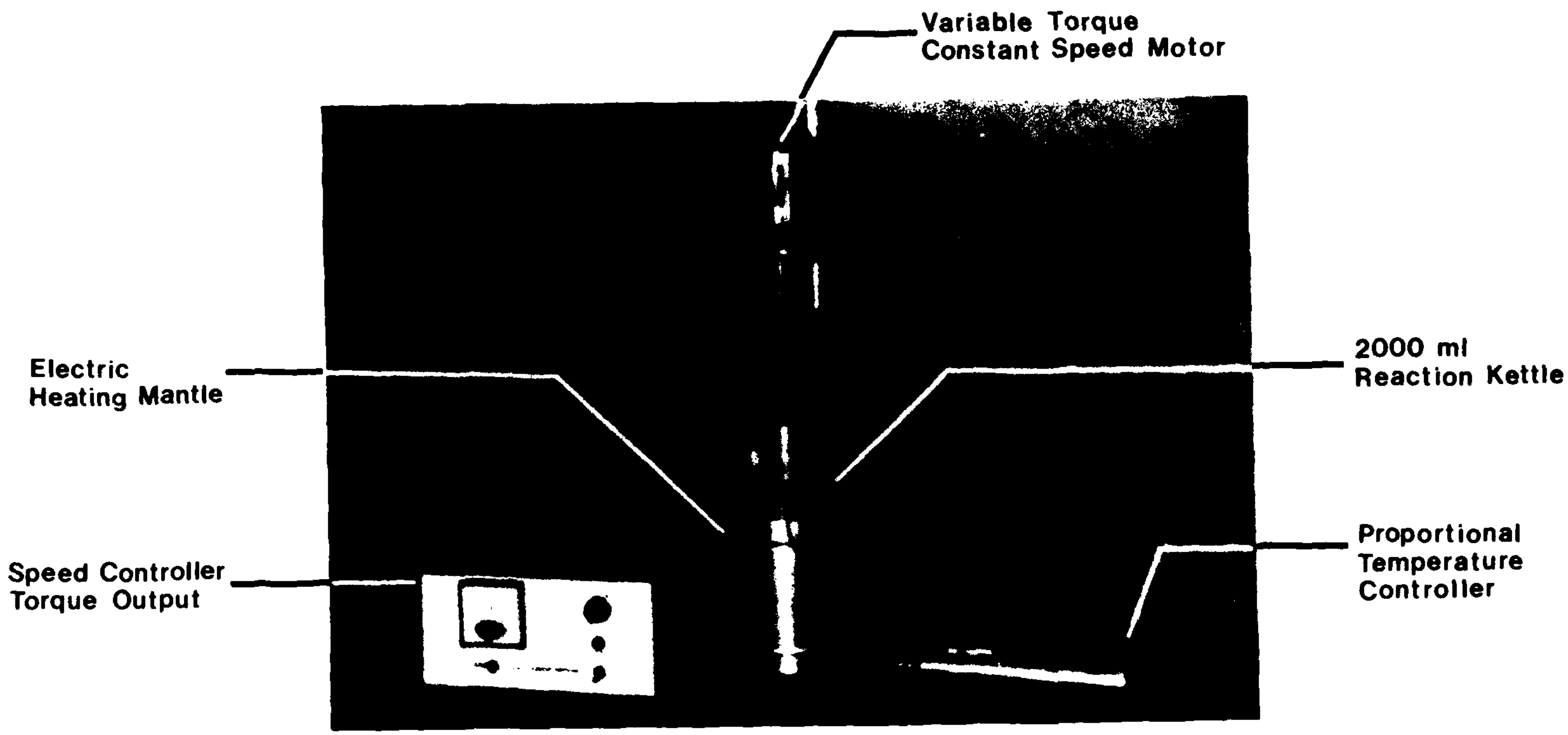


Figure 15. Suggested Equipment Set-Up for Laboratory Production of Asphalt-Rubber Material. (Reference 18)

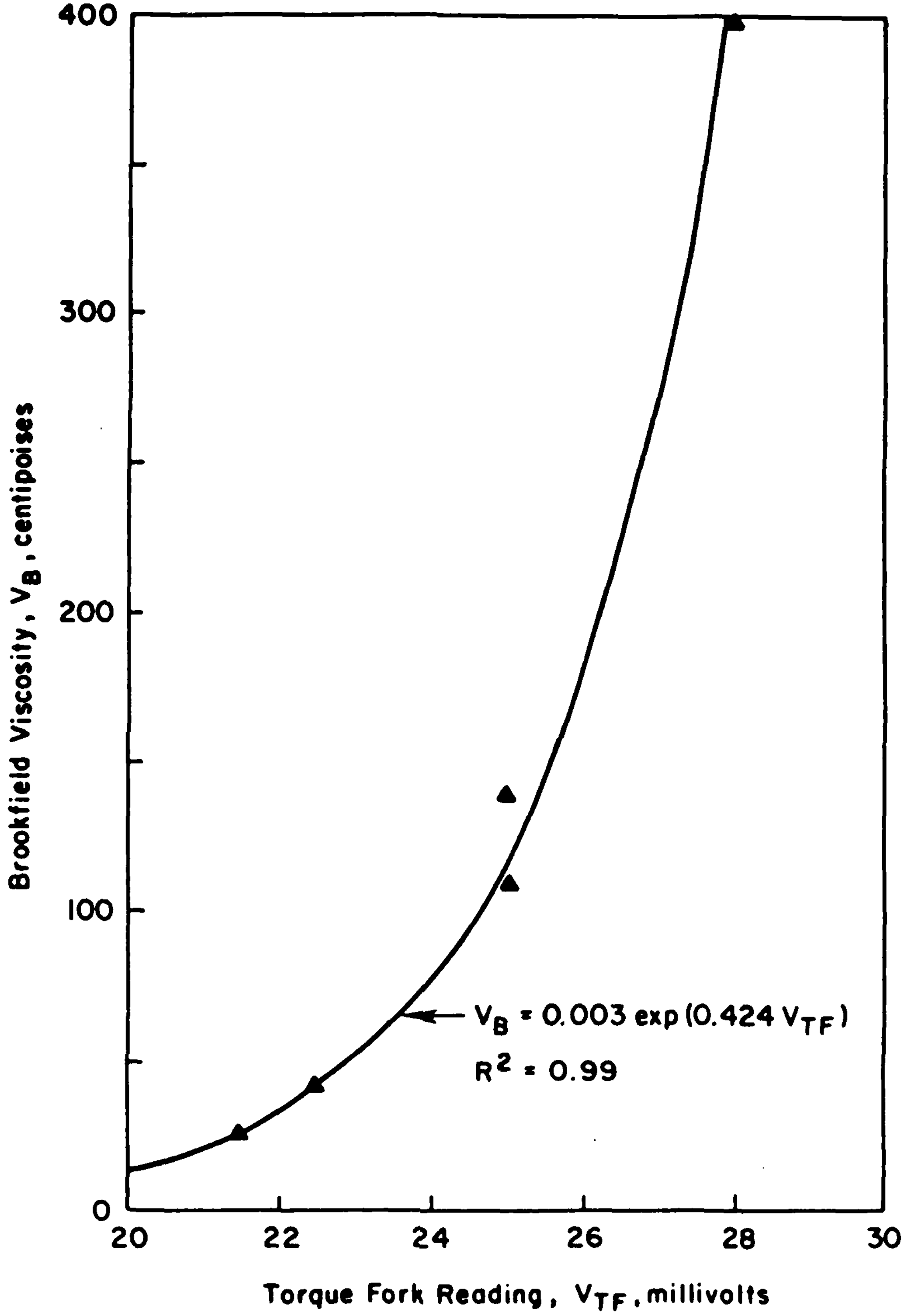


Figure 16. Relationship Between Output of Stirring Device and Brookfield Viscometer. (Reference 18)

as the rubber has been added and the environment of the flask secured.

Step 3. Continue reacting the asphalt-rubber for not less than one hour or until the output from the stirrer reaches a uniform level. The reaction time is a function of the type, morphology, concentration, and gradation of the rubber materials and can vary considerably, as seen in Figures 10, 13 and 14 and the discussion or laboratory production of asphalt-rubber.

Step 4. Upon completion of blending, the asphalt-rubber is ready for mixing with aggregates or the material can be poured into suitable containers, and cooled to room temperature awaiting use in the mixture design phase of testing.

NOTE: Appendix A contains a list of equipment models that should be suitable for use in laboratory preparation of asphalt-rubber.

CHAPTER 3. ASPHALT-RUBBER CONCRETE MIXTURE DESIGN

BACKGROUND

While asphalt-rubber materials have been used extensively in seal coat and interlayer construction, only a limited amount of experimental work has been done using asphalt-rubber as a binder in asphalt concrete construction. Some of the earliest work reported in the literature was by Jimenez (Ref 20) in 1979 and later (Ref 15) in 1982. Jimenez prepared the asphalt-rubber using the same techniques and formulations as those used for seal coats, membranes, and interlayers in Arizona. The aggregate Jimenez used was that for a standard dense-graded surface course with a top size of 3/8 inch. He also investigated an open graded mixture for possible use as a replacement for chip seals.

Jimenez used two different methods of compaction for the hot mixed rubber-asphalt concrete:

1) The Triaxial Institute Compactor, also known as the California kneading compactor, using test method ARIZ 803, and
2) The Vibratory Kneading Compactor described in Reference 21.

Both of these methods employ techniques for applying compactive energy that is considerably different from that in the standard Marshall Test Method used by the Federal Aviation Administration (Ref 22).

Jimenez observed a number of differences between the behavior of the asphalt-rubber concrete specimens and a standard asphalt concrete. He noted that, after compaction with the California kneading compactor, it was necessary to leave the asphalt-rubber concrete specimens in the mold for three days because, if extracted before then, the specimens would swell up to the point of cracking and the radial dimension would increase so much that the specimens would not fit into the Hveem stabilometer shell. None of the other researchers who have prepared asphalt-rubber concrete specimens have reported a significant problem with swelling of specimens (Refs 19 & 23). In this study, some swelling of the asphalt-rubber concrete specimens was experienced upon extrusion from the molds. The problem was solved by allowing the specimens to cool in the molds to room temperature before extrusion. This took no longer than 24 hours. In both references 19 & 23 and in this study, the Marshall hammer was used for specimen compaction. During testing Jimenez found that the asphalt-rubber specimens would not hold the confining pressure without a preload applied before Hveem testing began.

Hveem specimens were also prepared using a modification of the vibratory kneading compaction procedure. The modification involved the application of a static load of 3770 pounds after vibratory compaction was completed. Apparently the swelling problems noted with the California kneading compactor did not occur with the vibratory kneading compactor (Ref 15).

Only a limited number of studies have been reported that used asphalt-rubber binders as defined in this report. Other studies have included the use of scrap rubber in an asphalt-concrete but the rubber is treated as an aggregate and not reacted with the asphalt before mixing with the aggregates. One of the latest articles of this type was presented at the 1986 annual meeting of the TRB and is included as Reference 24. That rubber modified asphalt concrete is marketed commercially as "Plusride" by All Seasons Surfacing Corporation of Bellevue, Washington.

The combinations of mixing and compaction conditions for asphalt-rubber concrete included in the literature cited above are delineated in Table 4. Notice that both the mixing and compaction temperatures are considerably higher than those used for asphalt concrete. The primary reasons for the higher than normal temperatures are: (1) the very high viscosity of the asphalt-rubber binder at typical mixing and compaction temperatures defined for the Marshall Method (Ref 22) and (2) the difficulty of wetting the aggregate surface with the asphalt-rubber which is more elastic than the untreated asphalt cement (Ref 26). It should be noted, however, that in the laboratory no problems have been reported with coating aggregate particles using standard mixing equipment (Refs 15, 20, & 23).

Table 4. Asphalt-Rubber Concrete Specimen Preparation Conditions Reported in the Literature

Reference	Compaction Type			Mixing Time, Min.	Temperature Conditions, °F		
					Mixing		Compaction
	California Kneading Compactor	Vibratory Kneading Compactor	75 Blow Marshall Hammer		Asphalt-Rubber	Aggregate	
15,20	x	x		2	375	300	2
19			x	N/I*	N/I**	N/I**	N
23			x	Until Coated	375	375	3
5			N/I**	N/I**	350	350	3

N/I* - Not included but reported that no problem experienced in mixing.

N/I** - Not included.

DEVELOPMENT OF THE MODIFIED MIXTURE DESIGN METHOD

Research Approach

Asphalt-rubber concrete was fabricated and tested in the laboratory. Two gradings of aggregate were evaluated using asphalt-rubber and conventional asphalt binders. Results of laboratory tests are compared with control asphalt concretes fabricated with identical aggregate types and gradations. The control mixtures were fabricated using conventional techniques for asphalt cement binder. The experimental mixes were fabricated using slightly modified techniques and two asphalt-rubber binders.

Materials

Two sources of asphalt-rubber were used for the experiments reported in this section of the report. These samples of the asphalt-rubber were obtained in the field from actual construction sites. Type A contained 25 percent rubber by weight and Type B contained 18 percent. The gradations of the rubber particles are shown in Figure 17.

Two standard laboratory aggregates used by TTI on numerous other research projects were used for the mix design. These aggregates are a subrounded river gravel obtained from a local Brazos River source and a limestone from near Brownwood, Texas. Gradations used for control asphalt concrete mixes are shown in Figure 18. While these gradations follow the lower edge of the FAA specification band, it was reasoned that mixtures in this region would be most critical and that fabrication procedures suitable for them would function properly for coarser gradations. A slight modification was made in the gradations of these materials to allow room for rubber particles in the mix. A blending of the rubber grading and modified mineral aggregate grading resulted in a combined gradation that matched the control aggregate gradation without rubber.

Control asphalt concretes were prepared consisting of AC-10 asphalt cement and subrounded river gravel and limestone at the gradations shown in Figure 18. Control asphalt concrete test results for the gravel mix were obtained from a recent study by Button, et al (Ref 27) while control asphalt

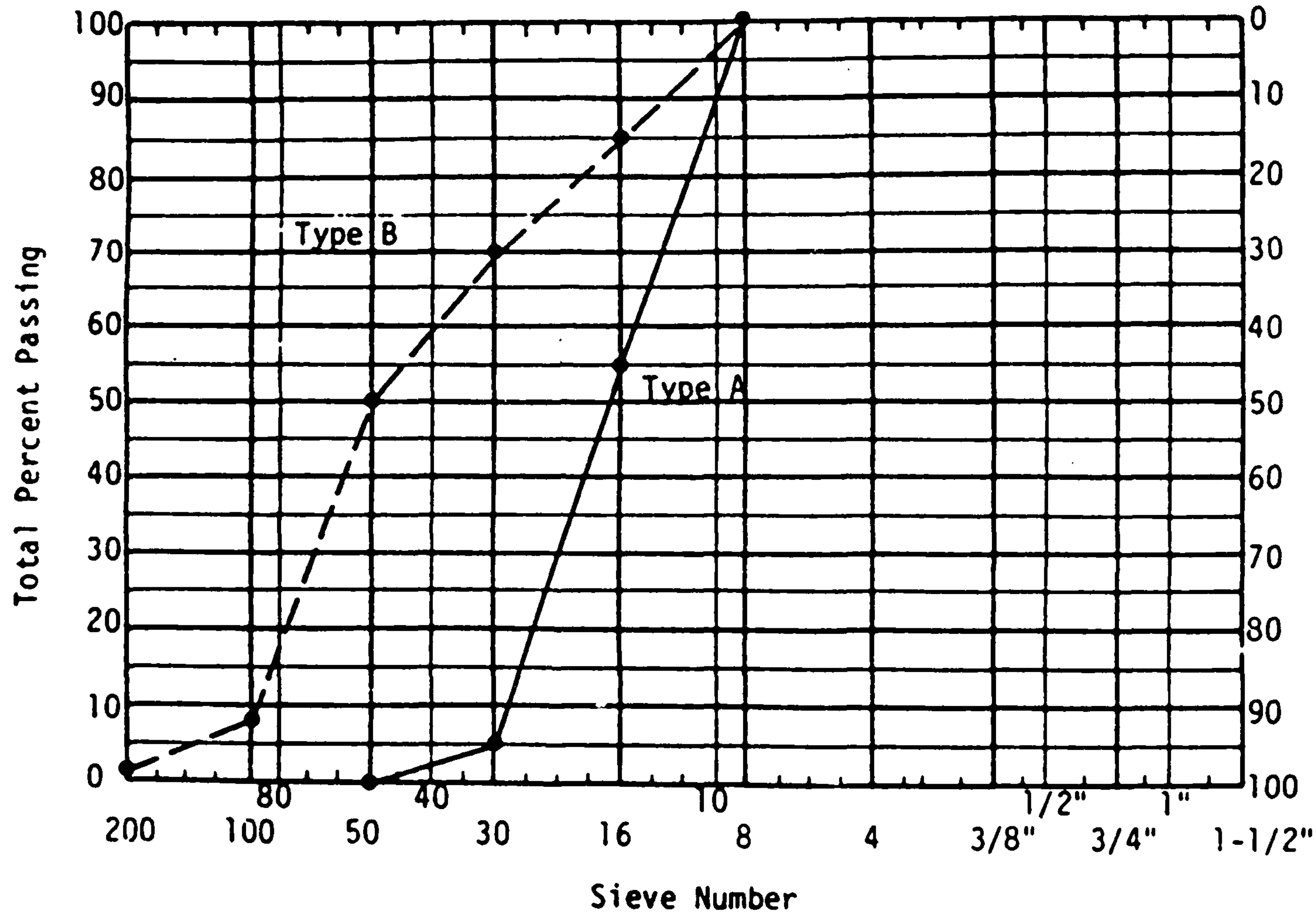


Figure 17. Rubber Gradations Used in the Asphalt-Rubber Binders.

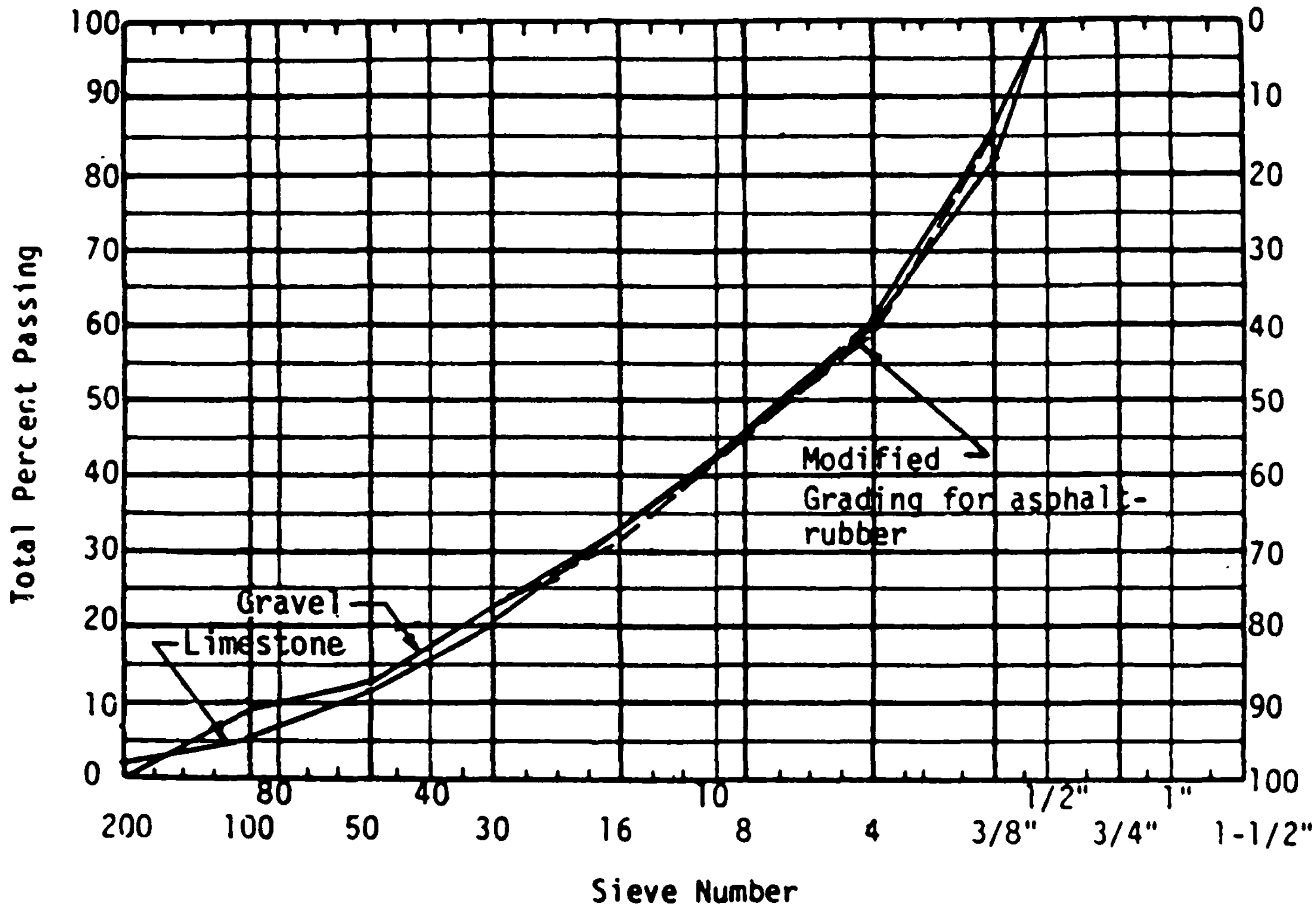


Figure 18. Gradations of Aggregates Used for Asphalt-Rubber Concrete.

concrete test results for the limestone mix were obtained during the course of this study.

Specimen Fabrication Experiment

To determine if the fabrication techniques for preparing laboratory specimens needed to be different from the standard Marshall Mixture Design Method, an experiment was performed that included variations in compactive effort and mixing and compaction temperatures. These experiments were conducted using the subrounded river gravel because (1) the principal investigators thought that this material would be most sensitive to variations in the viscosity of the asphalt-rubber with temperature and (2) because subrounded gravel is relatively easy to compact, variations of the mixtures in response to compactive effort would primarily reflect the effect of the asphalt-rubber binder.

The fabrication experiment was conducted at a binder content of 5.5 percent by weight of the aggregate in order to yield an air void content between 6 and 8 percent. This range of air void content was selected in order to allow comparisons between the properties of the asphalt-rubber concrete and the control mixtures which were prepared with air void content between 6 and 8 percent to allow moisture susceptibility tests using the modified Lottman conditioning procedures.

Experiment Design. Asphalt-rubber concrete samples were fabricated at 5.5% binder by weight of aggregate using the Marshall method of compaction. Three different blow counts and three different temperatures were used to determine an optimum fabrication technique using the combinations shown in Figure 19. Since this portion of the study was a cooperative venture with projects being performed for the FHWA and Texas State Department of Highways and Public Transportation, the following tests were performed on all specimens:

		Marshall Compaction, blows		
		25	50	75
Compaction Temp, F	275			
	325			
	375			

Figure 19. Specimen Fabrication Technique Experiment Design.

1) Marshall Stability, lbs

2) Hveem Stability, %

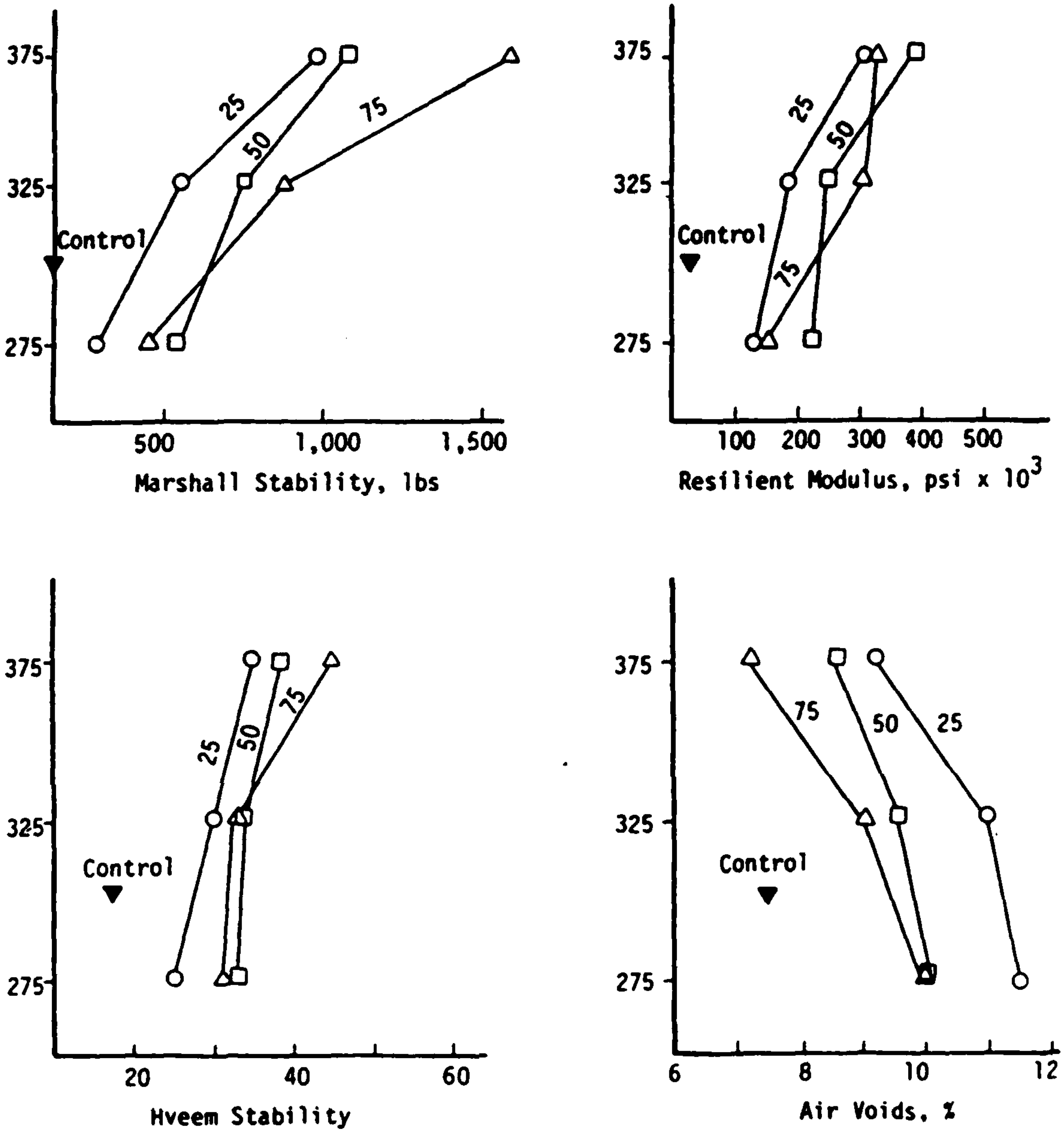
3) Resilient Modulus @ 77F, psi

4) Air Voids, %

Evaluation of Results. Tests were performed on specimens fabricated at the various temperatures and compactive efforts shown in Figure 19. The test results are shown in Figure 20. Test results for Marshall stability show that both the compactive effort and compaction temperature have a very significant effect on the Marshall stability. Even at the low compactive effort, a compaction temperature of 375°F reduces the viscosity of the asphalt-rubber at compaction sufficiently for the compacted specimen to show a stability much higher than that of the control asphalt concrete with an AC-10. The additional compactive effort from 25 to 75 blows produces a mixture with an increase in stability at 375°F of about 50 percent. The Hveem stability is fairly insensitive to temperature and number of blows of compaction. This is a reflection of the fact that Hveem stability is largely a measure of aggregate interlock and friction and is not very sensitive to binder viscosity. Once the aggregates achieve a fairly dense state, the Hveem stability does not change much with changes in binder viscosity.

The air void content is fairly sensitive to both compaction effort and temperature. The air void content generally decreases as either mixture temperature increases or as compactive effort increases. Notice that only at 75 blows per face does the air void content approach the selected value of 7 percent. This perhaps reflects the difficulty of compacting fine-dense graded mixtures.

Resilient modulus is less sensitive to the compactive effort than to the compaction temperature. There is generally an increase in resilient modulus with an increase in both temperature and compaction effort. However, since the Marshall Mixture Design Method does not include resilient modulus, more emphasis was placed on the sensitivity of Marshall stability and air void content to fabrication conditions.



Note: Numbers on curves are number of compaction blows per specimen face.

Figure 20. Asphalt-Rubber Concrete Properties for Fabrication Experiment Using G'avel Aggregate and Rubber B.

Since there is a very clear effect of temperature and compactive effort on both Marshall stability and on void content, it is not difficult to determine that both the highest temperature and compactive effort should be used in fabricating the asphalt-rubber concrete specimens for mixture design and, in fact, the major modifications to the current MS-2 manual procedures include modifications of the mixing and compaction temperatures.

Sample Mixture Design

An example mixture design was performed in the laboratory to evaluate the modification to the design procedure and to verify that a satisfactory design could be developed using crushed materials and a different asphalt-rubber. Therefore, a mixture design was developed using the crushed limestone with the gradation shown in Figure 18 and with Type A asphalt-rubber. The modifications to the standard MS-2 procedure included:

1) Adjusting the aggregate grading to permit space for the rubber particles-- in essence the rubber was treated as an additional aggregate.
2) Mixing and compaction temperatures were 375°F, therefore, the aggregates and the asphalt-rubber were heated to 375°F before mixing
3) Compaction effort was 75 blows per face without regard to gear load.
4) Mixing was performed using a high energy mechanical mixer.
5) Specimens were allowed to cool to room temperature before being extruded from the molds.

Using these modifications, three specimens were prepared at each of the follow asphalt-rubber contents:

4.5

5.5

6.0 % asphalt-rubber by weight of aggregate

7.5

8.5

The results of testing are contained in Figure 21 for the standard plots used in the Marshall Mixture Design procedure. These plots show behavior similar to that expected from any dense graded aggregate and the design laboratory asphalt content is 6.7 percent based on:

Property	% Asphalt-Rubber
Optimum for Maximum Stability	6.2
Optimum for Bulk Specific Gravity	7.2
Median for Air Void Content	6.7
AVG = 6.7%	

Summary

A set of modifications to the standard FAA method of mixture design procedure has been suggested that will permit the use of asphalt-rubber instead of asphalt in asphalt concrete. The only rubber included in this investigation was that produced by grinding scrap tires. The suggested modifications were developed based on the results of an experiment involving a range of mixing and compaction temperatures and compactive efforts. A mixture design was performed on a different asphalt-rubber and aggregate from that used to develop the modification. No problems were encountered in the conduct of the mixture design or in the analysis of the test results.

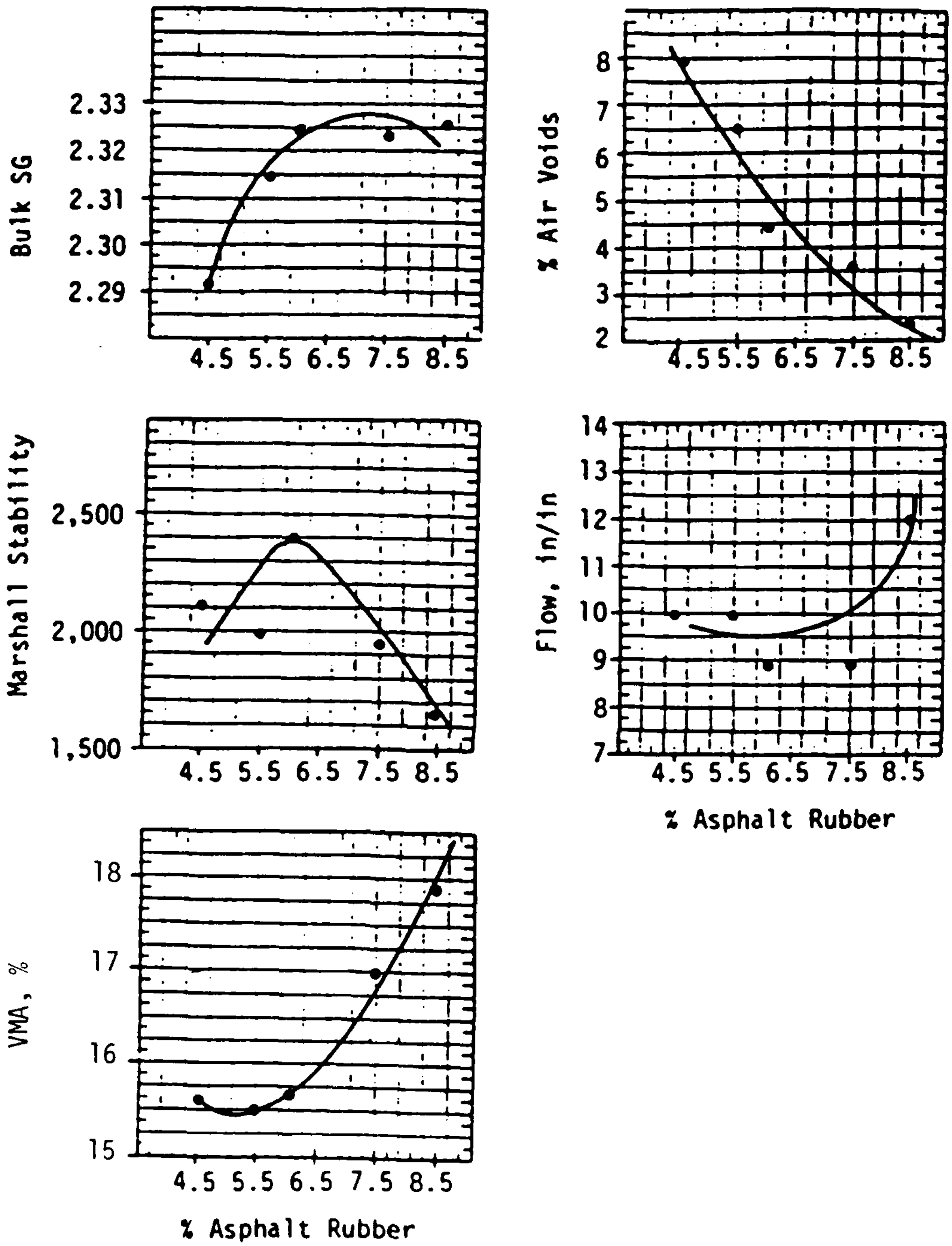


Figure 21. Asphalt-Rubber Concrete Mixture Design Results for Type A Asphalt-Rubber.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

The primary objectives of this report were to define the laboratory conditions necessary for producing a mixture design of asphalt-rubber concrete. Because laboratory tests used to evaluate the properties of asphalt-rubber are not defined sufficiently for specification purposes, a procedural method has been included for preparation of the asphalt-rubber for both the laboratory (Appendix A) and the field (Appendix B).

Within the bounds of the experiments presented in this report, the following conclusions and recommendations are appropriate for mixture design of asphalt-rubber concretes.

1. Laboratory produced blends of asphalt-rubber binder using the same combination of asphalt and ground scrap tire rubber as in field installations have been shown to exhibit similar properties. Therefore, laboratory prepared materials should exhibit characteristics similar to those prepared in the field.
2. Reacted asphalt-rubber binders can be produced in the laboratory in quantities sufficient for use in asphalt-rubber concrete mixture design using a modification of the Marshall Method of Mixture Design. These reacted materials can be prepared beforehand, cold-stored, and reheated for use in mixture design with no apparent effect on binder characteristics.
3. A laboratory procedure for producing asphalt-rubber binders has been included in this report along with a list of suggested equipment and suppliers.
4. Coating aggregates with hot asphalt-rubber is easily accomplished using a mechanical laboratory mixer at temperatures well below those needed for compaction, 375°F.
5. The aggregate gradation should be modified to allow space for the ground rubber. This is most easily accomplished by considering the rubber to be an extra aggregate.

6. For Marshall hammer compaction of asphalt-rubber specimens, 75 blows per face at a temperature of 375°F appears adequate.
7. Successful mixture designs can be accomplished in the laboratory using the procedures suggested in this report. Mixtures prepared with asphalt-rubber binders exhibit higher stabilities than similar mixtures made with asphalt cement.
8. It is recommended that field trials be conducted using dense graded materials in order to determine if these recommendations are applicable to a wider range of materials.

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Appendix A. Laboratory Equipment for Use in Producing Asphalt-Rubber

This appendix contains a list of equipment that should be suitable for use in laboratory production of asphalt-rubber. This list is not comprehensive but simply representative of the equipment available as off the shelf items.

1. Inductive Motor Stirrer
   a) Fisher Stedi-Speed Stirrer, No. 14-498A for 115V
   b) Cole Parmer Servodyne- Standard Servodyne system no. K-4440-00
2. Proportional Temperature Controller
   a) Fisher Proportional Termperature Controller, No. 15-177-50 with probe no. 15-177-57
   b) Cole Parmer-Microprocessor-based temperature controller, No. K-2165-00
3. Electric Heating Mantles
   Fisher cylindrical mantle for round bottom flasks, No. 11-471-5D
4. Flasks
   Pyrex Three Neck with 24/40 ground glass joints

Appendix B. Suggested Guide Specification for Asphalt-Rubber Binder

This appendix is the product of three project consultants who have worked with asphalt-rubber since organized laboratory investigations began in the late 1970's:

Dr. Ray Pavlovich

Dr. Rudy Jimenez

Dr. Scott Shuler

These suggested specifications are the result of continuous set of activities involving not only their research but also activities in ASTM; therefore, these guide specifications represent the best technical experience available today.

1. DESCRIPTION:

This work involves production of asphalt-rubber binders for use in hot asphalt-rubber concrete for pavement surfaces in accordance with the plans and other specifications.

This specification describes two known proprietary processes for production of the binder hereinafter known as Method A and Method B. Method A uses ground reclaimed "devulcanized" rubber and an extender oil whereas Method B uses ground reclaimed vulcanized rubber and a kerosene diluent. Either method is acceptable based on proper compliance with the specifications and certification of materials.

2. MATERIALS:

2.01 ASPHALT CEMENT. Asphalt cement shall meet the requirements of AASHTO M 20-70 (Table 1.), M226-80 (Table 1.), or M226-80 (Table 3). Acceptable grades for the respective materials will depend on location and circumstances and will require approval of the Supplier of the Asphalt-Rubber. In addition, it shall be fully compatible with the ground rubber proposed for the work as determined by the Supplier.

2.02 RUBBER EXTENDER OIL (METHOD A). Extender oil shall be a resinous, high flash point aromatic hydrocarbon meeting the following test requirements;

Viscosity, SSU, at 100 F (ASTM D 88)	2500 min.
Flash Point, COC, degrees F (ASTM D 92)	390 min.
Molecular Analysis (ASTM D 2007):	
Asphaltenes, Wt.%	0.1 max.
Aromatics, Wt.%	55.0 min.

2.03 KEROSENE TYPE DILUENT (METHOD B). The kerosene type diluent used shall be compatible with all materials used and shall have a flash point (ASTM D 92) of not less than 80F. The initial Boiling Point shall not be less than 300F with total distillation (dry point) before 450F

(ASTM D 850). The Contractor is cautioned that a normal kerosene or range oil cut may not be suitable.

2.04 GROUND RUBBER COMPONENTS:

A. FOR METHOD A. The rubber shall meet the following physical and chemical requirements:

1. COMPOSITION. The rubber shall be a dry free flowing blend of 40 Wt.% powdered devulcanized rubber and 60 Wt.% ground vulcanized rubber scrap specially selected to have a natural rubber content of at least 40 Wt.% of the rubber. It shall be free from fabric, wire, or other contaminating materials except that up to 4 WT.% of a mineral powder (such as calcium carbonate) may be included to prevent sticking and caking of the particles.

2. SIEVE ANALYSIS (ASTM C 136)

Sieve Number	% Passing
8	100
30	60 - 80
50	15 - 40
100	0 - 15

3. CHEMICAL ANALYSIS (ASTM D 297):
Natural Rubber Content, Wt.% 30 min.

4. MILL TEST:
When 40 - 50 grams of rubber retained on the Number 30 sieve are added to the tight 152.4 mm rubber mill, the material will band on the mill roll in one pass, and will usually be retained on the mill roll. This will indicate the presence of a sufficient quantity of reclaimed devulcanized rubber.

B. FOR METHOD B. The rubber shall be a ground tire rubber, 100% vulcanized, recommended by the Contractor for this use and with the approval of the Engineer and meeting the following requirements:

1. COMPOSITION. The rubber shall be ground tire rubber, dry and free flowing. The specific gravity of the rubber shall be 1.15 +/- 0.05 and shall be free from fabric, wire or other contaminating materials except that up to 4 Wt.% of a mineral powder (such as calcium carbonate) may be included to prevent sticking together of the particles.

2. SIEVE ANALYSIS (ASTM C 136):

Sieve Number	% Passing
8	100
10	98-100
30	0-10
50	0-2

2.05 CERTIFICATION AND QUALITY ASSURANCE. Prior to production, the Contractor shall submit certification of specification compliance for all materials to be used in the work. Also certification shall be submitted concerning the design of the asphalt-rubber blend as follows:

A. METHOD A. The Contractor shall submit certification that the asphalt cement is compatible with the rubber and has been tested to determine the quantity of extender oil (usually 1 to 7 Wt.%) required and that the proposed percentage will produce an absolute viscosity of the blended materials of 600 to 2000 poises at 140 F when tested in accordance with the requirements of AASHTO T 202-80. New certifications will be required if the asphalt cement lot or source is changed.

B. METHOD B. The contractor shall submit certifications that the asphalt cement is compatible with the rubber. New certifications will be required if the asphalt cement lot is changed.

3. EQUIPMENT:

3.01 PRE-BLENDING. Rubber and a portion of the asphalt for the asphalt-rubber blend shall be preblended in a master batch prior to introduction of the master batch to the distributor. The master batch can be diluted with additional asphalt and additives in the distributor to the formulation recommended by the Supplier.

4. PRODUCTION DETAILS:

4.01 PREPARATION OF BINDER: METHOD A.
A. PREPARATION OF ASPHALT - EXTENDER OIL MIX BLEND. Blend the preheated asphalt cement (250 to 400 F), and sufficient rubber extender oil (1 to 7 Wt.%) to reduce the viscosity of the asphalt cement-extender oil blend to within the specified viscosity range. Mixing shall be thorough by recirculation, mechanical stirring, air agitation, or other appropriate means. A minimum of 400 gallons of the asphalt cement-extender oil blend shall be prepared before introduction of the rubber.

B. PREPARATION OF ASPHALT-RUBBER BINDER. The asphalt-extender oil blend shall be heated to within the range of 350 to 425F. The asphalt-rubber blend for the master batch shall be preblended in appropriate preblending equipment as specified by the supplier prior to introduction of the master batch into the distributor. Addition of asphalt cement into the distributor to provide the specified formula shall be as directed by the supplier. The percentage of rubber shall be 20 to 24 Wt.% of the total blend as specified by the supplier. Recirculation shall continue for a minimum of 30 minutes after all the rubber is incorporated to insure proper mixing and dispersion. Sufficient heat should be applied to maintain the temperature of the blend between 375 and 425 F while mixing. Viscosity of the asphalt-rubber shall be less than 4000 centipoises at the time of application (ASTM D 2994 with the use of a Haake type viscometer in lieu of a Brookfield Model LVF or LVT is desired).

4.02 PREPARATION OF BINDER: METHOD B.

A. PREPARATION OF THE ASPHALT-RUBBER BLEND-MIXING. The asphalt cement shall be preheated to within the range of 350 to 450F. The asphalt-rubber blend for the master batch shall be preblended in appropriate preblending equipment as specified by the supplier prior to introduction of the master batch into the distributor. Addition of asphalt cement and diluent into the distributor to provide the specified formula shall be as directed by the supplier. The percentage of rubber shall be 20 to 24 Wt.% of the total asphalt-rubber mixture (including diluent). Mixing and recirculation shall continue until the consistency of the mixture approaches that of a semi-fluid material (i.e., reaction is complete). At the lower temperature, it will require approximately 30 minutes for the reaction to take place after the start of the addition of rubber. At the higher temperature, the reaction will take place within approximately five minutes; therefore, the temperature used will depend on the type of application and the methods used by the Contractor. Viscosity of the asphalt-rubber shall be less than 4000 centipoises at the time of application (ASTM D 2994 with the use of a Haake type viscometer in lieu of a Brookfield Model LVF or LVT if desired). After reaching the proper consistency, application shall proceed immediately.

B. ADJUSTMENT TO MIXING VISCOSITY WITH DILUENT. After the full reaction described in MIXING (4.02) above has occurred, the mix can be diluted with a kerosene type diluent. The amount of diluent used shall be less than 7.5 percent by volume of the hot asphalt-rubber composition as required for adjusting viscosity for spraying or better wetting of the aggregate. Temperature of the hot composition shall not exceed the kerosene initial boiling point at the time of adding the diluent.

4.03 JOB DELAYS. Prior to preparation or use of asphalt-rubber (Prepared by either Method A or B), maximum holdover times due to job delays (time of application after completion of reaction) to be allowed will be agreed upon between the Contractor, Supplier, and Engineer. However, holdover times in excess of 16 hours will not be allowed at temperatures above 290F. Retempering including reheating and the addition of asphalt, rubber or diluent (kerosene/extender oil) will be allowed with the approval of the Engineer.

4.04 APPLICATION OF BINDER. The material shall be supplied to the drum or pugmill at a temperature of 375 to 425 F for Method A and 290 to 350 F for Method B.

5. METHOD OF MEASUREMENT:

The asphalt-rubber binder will be measured by the number of tons of material actually used.

6. BASIS OF PAYMENT:

The unit price bid per ton shall include the cost of furnishing all material, all labor and equipment necessary to complete the work.

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